A METHODOLOGY FOR TOPSIDE DESIGN AND INTEGRATION IN PRELIMINARY WARSHIP DESIGN

by

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ABSTRACT

This thesis investigates warship topside design and integration and proposes a methodology that provides, during the preliminary design stages, an enhanced topside design capability above that currently available. The feasibility of such a system is demonstrated through a number of individual investigations and ship design studies for both conventional and unconventional naval vessels. A recommended implementation of the methodology, integrating it with the recently produced layout system, is proposed as the way forward.

Topside design is a complex task resulting from the requirement to locate all the necessary equipment on the weatherdeck and superstructure of a warship whilst minimising interactions. The current tools and design methodologies fail to cohesively address design issues at the concept stage. This is often due to the specialist nature of the analyses, which require detailed definitions only available later in the design process as well as expert knowledge in the application of the techniques. The proposed methodology provides guidance as different design solutions are developed and evaluated, allowing earlier identification of potential problems. It operates in an 'open' manner providing the naval architect with the flexibility to investigate and analyse the design as it evolves without dictating design decisions or requiring expert application knowledge.

The major issues that need to be considered during preliminary warship design are discussed. Current design methods and the shortfalls associated with each of them are considered. A methodology is outlined detailing the principles that are applicable and the important components and characteristics of any solution identified. The major aspects in topside integration are investigated and design tools proposed and evaluated. A framework for the integration of these tools is developed which is suitable for implementation using current computer technology. The suitability of this framework to incorporate other less complex but important topside design issues is evaluated and appropriate techniques identified.

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NOMENCLATURE

a) Abbreviations

3D	Three Dimensional
AAW	Anti Aircraft Warfare
AI	Artificial Intelligence
ASW	Anti Submarine Warfare
ASuW	Anti Surface Warfare
BAM	Blockage Assessment Model
B.Eng.	Bachelor of Engineering
CAD	Computer Aided Design
CEC	Co-operative Engagement Capability
CIWS	Close in Weapon System
CFD	Computational Fluid Dynamics
CNGF	Common New Generation Frigate
CONDES	Concept Design System for Ships (MOD)
CPO	Chief Petty Officer
CVN	Attack Carrier (Nuclear Propulsion)
DD	Destroyer
DDG	Guided Missile Destroyer
DERA	Defence Evaluation and Research Agency
DOD	Department of Defence (US)
DOS	Disk Operating System
DRA	Defence Research Agency
ECM	Electronic Countermeasures
EMC	Electromagnetic Coupling
EMI	Electromagnetic Interference
ESM	Electronic Support Measures
EW	Electronic Warfare
FEMIT	First Option Electromagnetic Mutual Interference Tool
FIR	Far Infrared
FPSO	Floating Production Storage and Offloading Systems
FSUC	Frequency Spectrum Utilisation Chart
GA	General Arrangement
GADS	General Arrangement Design System
GPS	Global Positioning System

GRC	Graphics Research Corporation Limited
GRP	Glass Reinforced Plastic
HF	High Frequency
HME	Hull, Machinery and Electrical
IDS	Ingegreria Dei Sistemi
IFF	International Friend or Foe
IGES	Initial Graphics Exchange Specification
IPM	Integrated Product Model
IR	Infrared
ITM	Integrated Technology Mast
ITDS	Integrated Topside Demonstration System
JEMIT	Joint Electromagnetic Interoperability Tool
JR	Junior Rate
LPD	Landing Platform Dock
MANEAC	Multiple Array Numeric Electromagnetic Analysis Code
MAVT	Multi Attribute Value Theory
M.Eng.	Master of Engineering
MF	Medium Frequency
MI-RADSIM	Mutually Interfering Radar Simulator
MIR	Middle Infrared
MIST	Mutual Interference Simulation Tool
MIT	Massachusetts Institute of Technology
MOD	Ministry of Defence (UK)
M.Sc.	Master of Science
NAME	Naval Architecture and Marine Engineering Department (UCL)
NARG	Naval Architecture Research Group (UCL)
NATO	North Atlantic Treaty Organisation
NBCD	Nuclear, Biological and Chemical Defence
NES	Naval Engineering Standard
NGS	Naval Gunfire Support
NIR	Near Infrared
NSS	NATO Sea Sparrow
PAAMS	Principal Anti-Air Missile System
PC	Personal Computer
PO	Petty Officer
RADHAZ	Radiation Hazard
RAS	Replenishment At Sea
RCMDS	Remote Control Mine Disposal System
RCS	Radar Cross Section

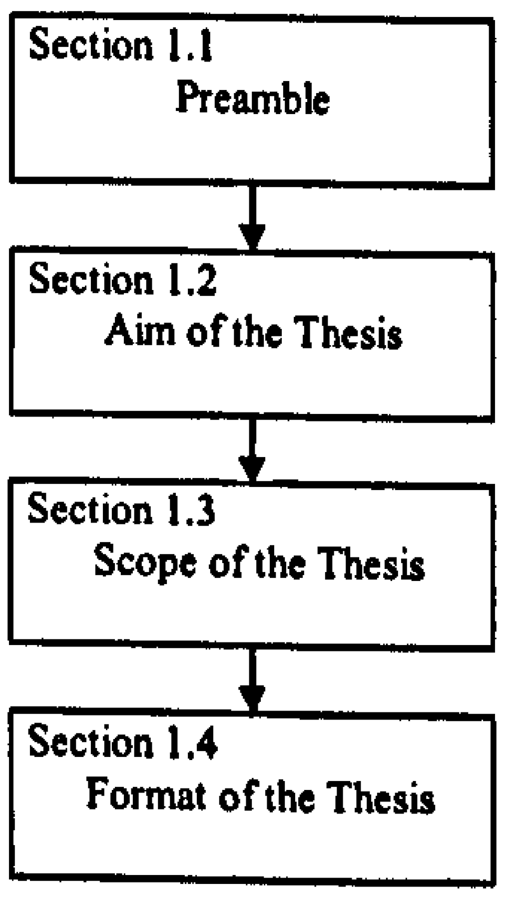
RF	Radio Frequency
RN	Royal Navy
SATCOM	Satellite Communications
SEMP	Ship Electromagnetic Prediction
SHIPIR/NTCS	Ship Infrared Signature Countermeasure and Threat Engagement Simulator
SIRCS	Single Island Radar Cross Section (UCL prediction tool)
SMITS	Shipboard Management Information Tracking System
STAN	Shipboard Technical Assistance Network
STEP	Standard for the Exchange of Product Model Data
STW	Safe to Work
SUBCON	Submarine Concept Design System
SURFCON	Surface Ship Concept Design System
SWATH	Small Waterplane Area Twin Hull
TDM	Topside Design Model
TOF	Time of Flight
UAV	Unmanned Air Vehicle
UCL	University College London
UHF	Ultra High Frequency
UK	United Kingdom
US	United States
USN	United States Navy
VHF	Very High Frequency
VLS	Vertical Launch Silo
XIR	Extreme Infrared

b) Symbols

a	Width of Plate, Cylinder or Ellipsoid, x axis (RCS analysis)	m
A_c	Area Captured by Radar Receiver	m^2
b	Height of Plate, Length of Cylinder or Ellipsoid, y axis (RCS analysis)	m
B	Beam On Waterline	m
C	Number of Chief Petty Officers	-
c	Height of Ellipsoid, z axis (RCS analysis)	m
C_B	Block Coefficient	-
C_M	Midships Coefficient	-
C_P	Prismatic Coefficient	-
C_W	Waterplane Coefficient	-
D	Depth	m
F	Freeboard	m
G	Antenna Gain	-
G_r	Antenna Receiver Gain	-
G_t	Antenna Transmitter Gain	-
h_d	Deck Head Spacing	-
J	Number of Junior Rates	-
k	Wave Number ($2\pi/\lambda$)	m^{-1}
k_B	Beam/Draught (B/T)	m
L	Length On Waterline	m
LBP	Length Between Perpendiculars	m
N	Complement	-
P	Number of Petty Officers	-
P_k	Probability of Kill	-
P_{min}	Minimum Level of Received Power from Signal	watts
P_r	Received Power	watts
P_t	Transmitted Gain	-
pv	Payload Volume	m^3
pw	Payload Weight	tonnes
p.v.f	Payload Volume Fraction	-
R	Number of Ratings	-
R	Distance from Antenna (RCS Prediction)	m
R_{max}	Maximum Detectable Range	m
S	Stores Endurance	days
T	Draught	m
te	Tonne	tonnes

V	Volume	m^3
V_m	Main Hull Volume	m^3
V_N	The Total Internal Volume Excluding Machinery	m^3
V_{req}	Total Volume Required at End of Sizing Loop	m^3
v_S	Superstructure Proportion	-
V_S	Superstructure Volume	m^3
W	Total Weight at End of Sizing Loop	tonnes
Y	Number of Officers	-
Δ	Displacement	tonnes
∇	Volume of Displacement	m^3
∇_G	Gross Volume	m^3
∇_N	Net Volume (Gross Volume - Volume of machinery and tanks)	m^3
π	Pi	-
ρ	Density	kg/m^3
ρ_m	Main Hull Displacement Proportion	kg/m^3
ρ_{ov}	Overall Density	kg/m^3
ρ_w	Density of Seawater	kg/m^3
θ	Angle from z-axis, Specular Co-ordinates, Local Axes (RCS analysis)	deg
λ	Wavelength	-
σ	Radar Cross Section, (RCS) of Target	m^2
ϕ	Angle in x-y Plane about the z-axis, Local Axes (RCS analysis)	deg

1. INTRODUCTION



1.1. Preamble

Advances in the technologies employed in warships have resulted in a greater amount of electronics as opposed to heavy weaponry. The space requirement for this additional electronic capability has increased whilst the weight of the armament has decreased [Eckhart 69], [Gates & Rusling 82], [Gates 87]. The traditional methods of basic ship concept design which were developed based on these early weight driven designs[1] have become less applicable to modern space driven designs [Honnor & Andrews 82], [Andrews 84a], [Andrews 86]. A research programme has been initiated by the Naval Architecture Research Group (NARG) of University College London (UCL) by Professor David Andrews to look at the application of methodologies to address the overall space driven ship design problem. This programme has been split into two major subject areas, the first addressing the needs of internal hull layout [Dicks 00], the second investigating the area of topside design and integration and resulting in this thesis. The outcome from the work carried out by Dicks [Dicks 00] was the proposal for a Building Block Methodology[2] [Andrews & Dicks 97], [Dicks 98]. The methodology demonstrated by Dicks' proposal is a working system similar to SUBCON [Andrews et al. 96]. This has recently been produced by UCL in conjunction with GRC Limited as a module in the Paramarine computer aided ship design system [Muñoz & Forrest 02], [Andrews & Pawling 03], [GRC 03]. The results from the topside studies form a companion system.

The research programme was centred on the preliminary design phase of an emerging ship design. During this preliminary phase there is no detailed definition of the ship, when design effort focuses on the relationships between operational capability and resultant ship volume and displacement, and results in a number of differing concept designs. It is the early stage of the design process where many

[1] Weight design algorithms suggest that each ship is a derivative of previous design. Most elements making up the ship can be estimated from a basis ship as a function of displacement. These weight equations are used to derive a displacement balance, allowing the investigation of varying capabilities [UCL 97]. Deviation from existing data is difficult [Andrews 84a].

[2] The core concept of the Building Block Methodology is that almost all design information is stored within a 'Building Block'. This contains the physical geometry, the functional description and weight. Whenever a design is created it can be balanced for gross size, functional features and layout of the geometric blocks.

differing design solutions are evaluated and compared [Andrews 94a]. It is important that at this stage the naval architect has a method to enable the consideration of all the topside issues as these can drive the overall size of the ship [Brown 87]. The importance of the topside arrangement is often overshadowed by the overall ship sizing process where, historically, the initial sizing has been a balance of weight and space with some consideration of powering and sensible hull parameters (e.g. C_P and C_M) [UCL 97]. Once a design methodology[3] is established that is responsive to the topside design issue this can be used in parallel with an internal hull design methodology so that the naval architect can provide a more satisfactory preliminary ship design ensuring the overall design process results in a more satisfactory solution.

Topside design and integration for a warship refers to the placement of all equipment that is located on the weatherdeck[4] and superstructure[5] of a naval vessel. It also refers to the arrangement of the superstructure itself and other items such as the masts, exhausts, flightdeck and helicopter hangar. The amount of equipment can be large and varied in nature requiring different placement issues to be resolved. For some items the only constraint is a geometric one, that is to ensure no physical clash occurs with other items of equipment and that access is available. For other equipment items the placement constraints are far more complex, for example, for weapon systems clear arcs of fire are important, as are sufficient blast and efflux areas for weapon exhaust. Radars and communication antennae emit radiation and additional constraints are placed on these items to ensure that they do not irradiate personnel, but also that they are suitably separated from other similar equipment to ensure minimum interference occurs. The topside arrangement is further complicated by the many items of equipment required to operate the ship safely, such as anchors and cables, safety equipment and replenishment rigs. Additionally the entire topside arrangement must be considered and evaluated to ensure it functions as a cohesive

[3] Design methodology is the study of the principles, practices and procedures of design in a broad and general sense. Its central concern is with how designing is and how it should be [Cross 84].
[4] The uppermost deck of a ship which is exposed to the weather at all times [Sullivan 95]. The exposed decks above the hull and above the superstructure [Gates 87].
[5] That part of a ship which is built on top of the upper deck [Sullivan 95]. Consists of the enclosed compartments and additional structure to support items of equipment.

system. Although many individual analysis techniques required to assess these differing requirements are, in theory, well established they are often not included in the design studies early enough to inform the naval architect about the impact of the choices made. Consequently design teams are often locked into choices made at the early stages of a design which result in far greater time and cost implications when the need to redesign is only identified far later in the design process.

1.2. Aim of the Thesis

The methodology presented is intended to be applicable during the initial investigatory stages of design when the level of design definition is 'broad brush' and substantially different concepts are being explored [Andrews 94a]. The methodology must allow for rapid investigation of different design solutions and provide design guidance to the naval architect which reveals possible design conflicts. It must operate in an 'open' manner allowing the naval architect the flexibility to investigate and analyse the design as it evolves, not dictate design decisions, or limit the user. Thus the following statement is presented as the aim of the thesis.

> ***To propose a methodology, applicable to all forms of surface naval vessel, that provides, for the preliminary design stages, an improved capability above that currently available to the naval architect when designing the warship topside environment.***

1.3. Scope of the Thesis

This thesis covers the research work that has been undertaken into the proposed topside design methodology developed to run concurrently with the Building Block Methodology developed by Dicks [Dicks 95], [Dicks 00]. The exploration of current deficiencies and the definition of the new methodology, including demonstration of the feasibility of proposed solutions, is detailed. This methodology is applicable to all forms of surface naval ships, monohull and multihull, in the concept phases of design, although consideration is given as to how the information would be passed into the more detailed stages of design. Although overall ship design is considered, this thesis does not discuss in detail the methodologies that exist for the sizing of a ship as a whole[6]. The research focused upon the warship topside and it is this that is presented here. The thesis does not cover the development of a final computerised tool. The research has focused on defining the methodology and associated tools, not the task of developing a workable software system but it does give a functional description of such a system (Chapter 8).

1.4. Format of the Thesis

The thesis is presented in five parts:-

- Formulation of the problem
- Conceptual solution
- Applicable methodologies
- Proposed solution
- System simulation

Figure 1.1 shows the chapters in each part and how the structure presents the topside design problem, a proposed methodology, evaluation of the major tools and concludes with a simulation of the topside design system.

The first part, consisting of Chapter 2, formulates the problem. The current approach to ship design is discussed and some of the traditional methods used to initially design a ship are outlined. Topside design is introduced and the current methodologies employed are detailed. Discussion on the current use of computer aided design tools for ship design as a whole and the more specific area of topside design is given. The chapter is supported by appendices detailing a numerical ship design procedure, as used at UCL, a topside design checklist and a background

[6] Sections of Chapter 2 discuss the task of overall ship design. As the thesis concentrates on warship topside design the area of overall ship design has to be considered. However, whilst Chapter 2 introduces the topic, greater emphasis is placed on the research topic for this thesis, that of warship topside design.

section summarising different topside configurations that exist in current warship designs as a point of reference.

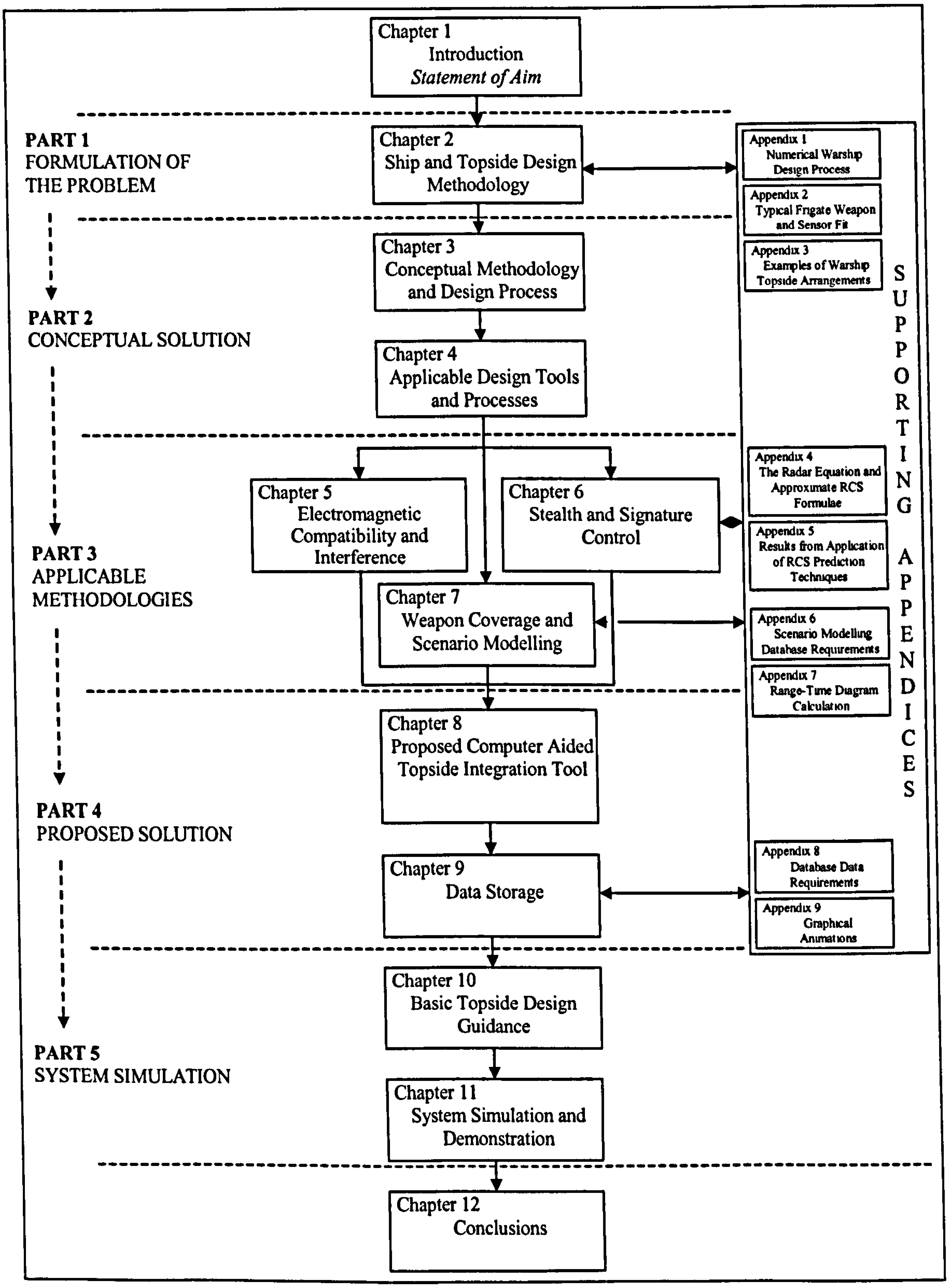


Figure 1.1 : Thesis Format

Part 2, containing Chapters 3 and 4, covers the conceptual solution. The underlying principles are explained followed by details on the important components and characteristics of a tool.

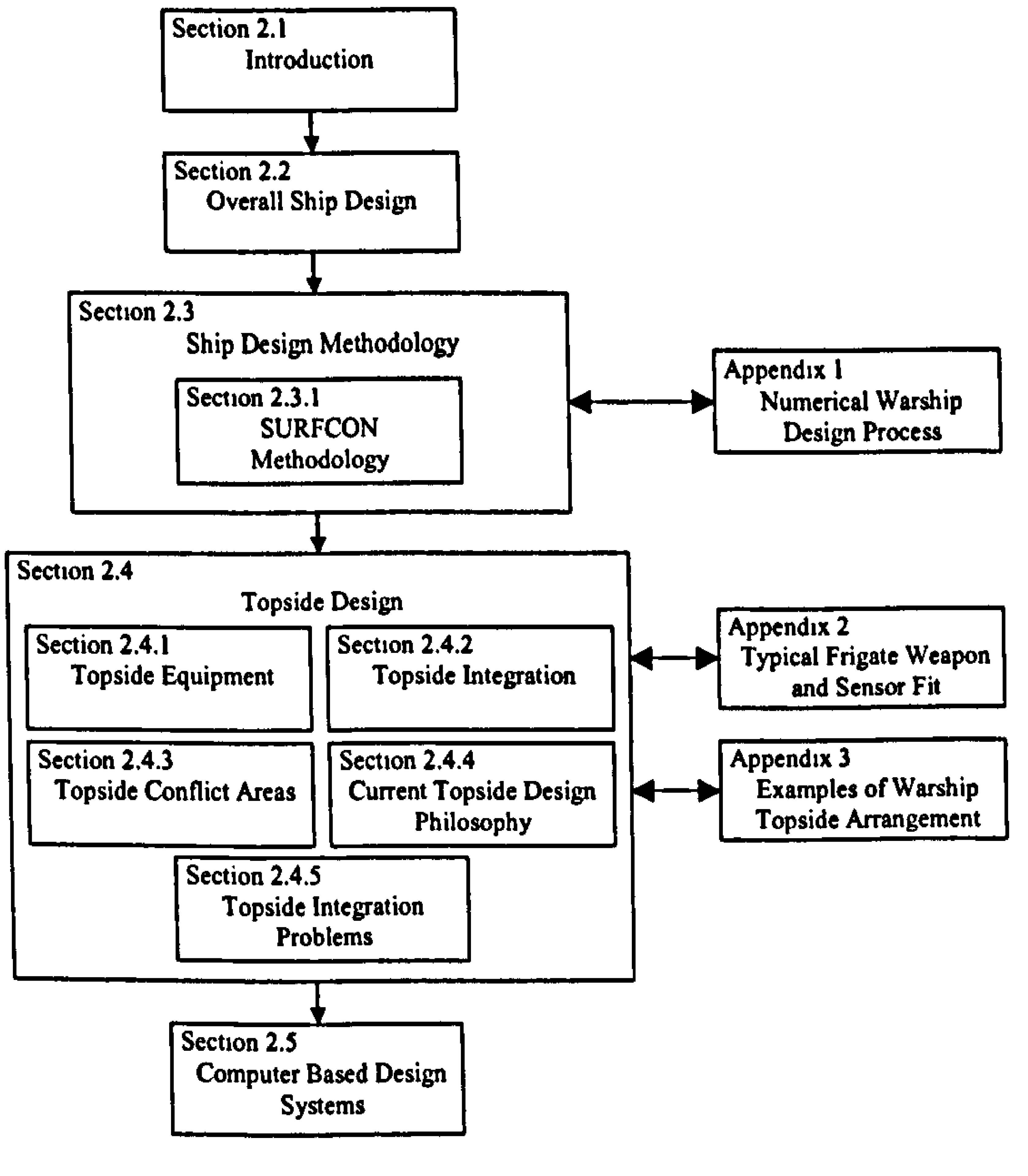
Part 3, covered by Chapters 5 to 7, details the investigations made into techniques available to address the three major areas of concern for topside design, namely electromagnetic compatibility and interference (Chapter 5), stealth and signature control (Chapter 6), and weapon coverage and scenario modelling (Chapter 7). These areas have to be catered for by the proposed topside design tool and the investigation of applicable design tools and guidance identifies the analysis required.

Part 4 of the thesis outlines the proposed solution (Chapters 8 and 9). With the knowledge gained from the investigations into the topside aspects covered in Chapters 5 to 7, a proposed solution for the topside design tool is developed. A framework is outlined that will allow the implementation of the topside tool identified and allow for further integration of other tools and design guidance. To facilitate the implementation of a practical tool meeting the proposed methodology the needs for data storage are identified (Chapter 9).

Part 5, on system simulation, covers two main areas. The first discusses how further basic design guidance can be captured within the proposed topside tool for use by the naval architect (Chapter 10). Demonstration of the type of analysis possible is given. Chapter 11 presents several design studies demonstrating how the tool benefits the naval architect in preliminary ship design studies by ensuring the topside arrangement is viable.

Concluding remarks are made in the final section of this thesis along with proposals for future work (Chapter 12).

2. SHIP AND TOPSIDE DESIGN METHODOLOGY



2.1. Introduction

In order to place the topside design task in context this chapter first considers the total ship design problem (Sections 2.2 and 2.3). Current design approaches are outlined, including the Building Block Methodology developed in conjunction with this research [Dicks 98], [Dicks 00] (Section 2.3.1). This provides a background for the topic of topside design. The problems encountered in topside design are outlined and typical approaches adopted to ease the topside design task are described (Section 2.4). The chapter concludes with a discussion on computer based design systems. A computer based approach is seen as applicable to the implementation of any new methodology (Section 2.5). Examination of current and proposed systems, for both total ship design and topside integration, provide a background for the remainder of the thesis.

2.2. Overall Ship Design

Warship roles are varied and the designs that result from these differing roles also vary in both overall size and design configuration. The most common form of ship design is the monohull, ranging in size from minesweepers [Harris 80], through escort designs [Purvis 74], [Thomas & Easton 93], to aircraft carriers [St Denis 66], [Honnor & Andrews 80]. Naval vessels are not limited to this monohull form, the most researched unconventional forms being the SWATH[7] [Betts et al. 87], [RINA 88] and the Trimaran [Pattison & Zhang 94], [Andrews & Hall 95], [Eddison & Summers 95], [Andrews & Zhang 95a], [Andrews & Zhang 95b], [Andrews & Zhang 96]. Whatever the resulting hullform, the final solution is often dominated by a design driver that is considered to be the most important factor for the particular ship. In some cases the design driver is obvious, such as the flight deck on an aircraft carrier, in others the design may be driven by a requirement to get a specific weapon to sea, or the driver may be the requirement for a particular characteristic such as increased stealth [Andrews 94a].

[7] SWATH - Small Waterplane Area Twin Hull ship. Essentially two cylindrical hulls located below the waterline linked by thin vertical struts and a cross deck structure.

The process of ship design has been described as a 'wicked' problem [Rittel & Webber 73], [Andrews 86], where it is difficult to divorce the solution from the initial requirement[8]. There is no simple sequential approach that produces a balanced design without considerable iteration, with each intermediate solution influencing a revised requirement. Despite the fact that ships have been designed and built since the early days of the dugout canoe there does not exist a simple formula that, when applied, will result in an optimum design[9], and it would not be reasonable to expect this. Indeed it is questionable whether an optimum solution for a given ship design can be defined [Andrews 90]. Andrews argues that preliminary ship design is not characterised by being highly structured, nor should it be. He states that mathematically sophisticated optimisation techniques leave the designer with a 'black box'[10] solution tool and that the mathematical optimisation techniques do not cater for the spatial elements that need to be considered in initial ship sizing.

The varying disciplines involved in design and the processes that are employed have led to design being described as an art and a science [Jones 70]. It is interesting to compare design, and in particular ship design, to other engineering and scientific analysis tasks. For a number of analysis tasks it can often be shown that there is a right and wrong answer to a particular problem[11]. This answer is often derived from fundamental principles. Design does not have this precision of proven principles and formulae to contain it, the process is one of ideas. It is this freedom that makes design such an interesting and challenging discipline but at all times the product must still meet any underlying fundamental principles on which correct operation depends. As a result the design engineer still has a framework in which to work but its boundaries are not fixed and while there are clearly wrong solutions there is no single right solution. The real essence of engineering design is that the designer has

[8] The 'wicked' problem is that the problem cannot be properly stated without regard to the solution [Andrews 86].
[9] Research has been carried out to investigate the use of optimisation techniques in ship design [Keane et al. 90].
[10] This is a where the reasons for the design decision is hidden from the user [Jones 70].
[11] This is a fairly simplistic view of engineering and scientific analysis. Popper discusses some of the true complexities in "The Logic of Scientific Discovery" [Popper 59]. Rather than correct answers, Popper introduces the concept that science attempts to find satisfactory explanations that lead us to further improve their satisfactoriness of explanation by improving their degree of testability.

to take the bold step of synthesis before they can analyse (using scientific principles), scientific analysis does not help with this synthesis stage[12]. A summary of general design theory and its influence on ship design is given by [Hoset & Erichsen 97][13] who discuss how design theory in general and in relation to ship design has progressed. They illustrate the complexities and many views discussed over the years from the early 1950's to the present day.

The process of designing and procuring a new ship, especially a complex warship, is a very involved and time-consuming process[14]. A broad outline of the stages involved is illustrated in a stepwise fashion below [Brown 92].

1. Pre-project phase
2. Concept phase
3. Feasibility phase
4. Contract definition
5. Detailed design
6. Production
7. In service
8. Disposal

At the Naval Architecture Research Group (NARG) at UCL research is focused on the preliminary phases. These preliminary phases can be thought of as covering the

[12] It can be argued that use of an optimisation approach or large-scale search methods (MonteCarlo/genetic algorithms) would allow scientific principles to be applied during this synthesis stage. It is the author's view that these methods are providing a method of searching a design parameter space characterised by, and synthesised from, previous design solutions, not performing original design synthesis.

[13] The paper by Hoset & Erichsen is a useful reference providing a single document that summarises a number of design papers from the early 1950s up to 1997. Further discussion within this thesis draws on the individual authors' work.

[14] A significant number of papers have been produced over the years detailing approaches to both ship design and procurements. Andrews has published extensively on this subject [Andrews 81], [Andrews 84a], [Andrews 86], [Andrews 93], [Andrews 94a], [Andrews 94b], [Andrews 98], [Andrews 00]. Other authors have discussed the design and procurement of warships from many differing points of view [Baker 55], [Watson & Gilfillan 77], [Reuter et al. 79], [Brown 86], [Brown 87], [Brown & Tupper 88], [Rains 90], [Ferreirro & Stonehouse 93], [Tibbets et al. 93], [Brown 95], [Betts 96], [Hoset & Erichsen 97], [UCL 97].

stages shown as stages 1 and 2 in the above list[15]. These can be thought of as the design phases where little detail about the required ship is known, other than a requirement that could be very vague. This could range from the requirement to get a new weapon system to sea, a definition of the required role, a specific equipment fit or a replacement for a current ship class.

The preliminary design stage[16] can be thought of as the design stage where the initial properties are defined and documented designs emerge. These preliminary design stages differ from the later stages as they require design synthesis to be carried out and the result from the preliminary work may be a revised requirement instead of, or as well as, initial design solutions [Hubka 82][17]. The later stages of design tend to concentrate on evolutionary development as the design progresses [Bryson 84], [Andrews 98]. All of the design decisions made during the preliminary stages will be reviewed and re-evaluated. This re-evaluation does not detract from the need to perform the preliminary design tasks fully. Whilst it is true that design decisions made at the initial stages will affect all subsequent outcomes [Suh 90], it is not possible to avoid making these decisions [Erikstad 96]. One aim of the preliminary design work is to ensure that all suitable designs are considered. This requires a full search of the design parameter space[18]. In the preliminary design stages the designer should propose and investigate many varying solutions to the problem. These then need to be investigated in sufficient detail to ascertain whether they present good alternatives. Therefore it is important to ensure that sufficient detail can be included at this stage so as to avoid building in constraints and features that may drive, or constrain, the design as the design progresses but may lead to less effective designs.

[15] Research work and the M.Sc. ship design exercise [UCL 97] at UCL does go into the feasibility phase and also into areas of detailed design and production but the research carried out focuses on concept and feasibility.
[16] The preliminary design stages are referred to by a number of different terms by different authors. Hubka refers to them as the "concept / conceptual design" stages [Hubka 82], whereas Bryson talks of "feasibility design" [Bryson 84].
[17] Hubka refers to the engineering design of mass produced products. However the results from his discussion can be considered applicable to the design of warships, a highly complex engineering product. Although a warship is not a mass produced product with prototypes during the development stages, the preliminary design work often results in revised requirements.
[18] Jones refers to this as "divergence in design" and states that it is required so as to have a large enough and fruitful enough search space [Jones 70]. A lack of divergence leads to the design being over constrained too early in the design process [Purcell & Gero 96].

The majority of major funding decisions with the bulk of cost consequences are made in the concept stages [Andrews 94a].

2.3. Ship Design Methodology

Traditional methods of ship design are based around the Design Spiral [Harvey-Evans 59], [Snaith & Parker 72] or modified versions of this spiral as is shown in Figure 2.1 [Andrews 81]. Andrews' representation avoids the closed, almost mechanistic, implication of the two-dimensional spiral. Despite unease about the descriptive adequacy, naval architects have found it useful, if only to indicate the iterative nature of the design process [Andrews 98]. This method, though successful in producing designs, can constrain a designer's flexibility and freedom in design.

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Figure 2.1 : Modified and Extended Design Spiral Process [Andrews 81]

Andrews has argued [Andrews 86] that, essentially, the process of ship design consists, at a technical level, of three fundamental and (currently) sequential subprocesses:-

- Initial sizing, where a gross size is obtained.
- A parametric exploration, where principal dimensions and hull form are evolved.
- An architectural and engineering synthesis, which is progressively performed within the constraints of the size and hull form previously determined.

The processes are shown in Figure 2.2 [Andrews 86], which illustrates the sequential nature of these tasks. Also indicated on the figure are details of the aspects brought to design creation by the individual designer, namely those associated with visual, linguistic and value schema [Daley 82]. In addition to these schema is an indication of the 'key generator' used both to determine the overall pattern or configuration and to guide subsequent design evolution [Darke 79][19].

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Figure 2.2 : Sequential Synthesis in Ship Design [Andrews 86]

Andrews concludes that this representation is still incomplete, as it fails to emphasise the effects of the multifarious constraints. Furthermore, representation as a set of feedback loops is inadequate both for certain design solutions (such as advanced hull forms) and also for a concurrent engineering approach [Andrews 98].

Figure 2.3 [Andrews 86] more closely represents the design process required for initial warship design. The sequential approach seen in Figure 2.2 is replaced by a single concurrent design block, resulting in the requirement to consider all ship aspects throughout the design process, bringing both form and architectural synthesis into the initial sizing process. Whilst, in a diagrammatic form, this approach allows the desired design evolution process to be achieved, applying it in practice was found to require a number of initial assumptions to allow the modified approach to work [Andrews 87].

[19] Darke carried out research into how architects actually arrive at their solutions to design problems and concluded that each had a 'key generator' [Darke 79].

Figure 2.3 : A Holistic Approach to a Fully Integrated Ship Synthesis [Andrews 86]

An initial deck plan was used to layout an arrangement of compartments at the early initial stages, this demonstrated the configurational viability of an initial design which had previously been obtained by no more than numerical balancing of weight and space. The investigations showed that for configurationally dominated designs the gross sizing, parametric survey, layout synthesis approach, as shown in Figure 2.2, was clearly not suitable and that the process shown in Figure 2.3 was a better approach, equally applicable to configurationally dominated designs and more conventional frigate/destroyer designs [Andrews 98]. Whilst the process described was a more coherent approach to initial ship sizing, applying it in practice was not easy and the need to make initial assumptions demonstrated that further research was required before the process illustrated in Figure 2.3 could be performed as intended.

The need to more coherently address the preliminary ship design, as a whole, as it progresses through the design process has resulted in research being carried out at UCL into computer aided design of warships with particular application to the concept phase [Dicks 98], [Dicks 00]. This research has stemmed from the change in the way in which the preliminary design is approached. With warships now containing a larger amount of electronics as opposed to heavy weaponry the design solutions are now space driven rather than weight driven [Andrews 86]. This has resulted in a need for a layout based design procedure as opposed to the existing method of using sizing algorithms based on information from past classes of ship[20]. These procedures are most often numerically based and involve a mathematically iterative approach to size the ship, the requirement is to balance the weight and space requirements of the ship. The algorithms are derived from previous ship designs, or input directly through knowledge of the individual system or equipment item, and often depend upon weight or space. By iterating through the process it is possible to achieve a mathematical balance. The designer will consider the influence of both internal and external layout, but the results from this do not feed directly into the numerical process. Using these traditional approaches it is possible to size a warship, based upon a weapon fit, endurance and similar parameters, without having to consider the layout[21]. A brief illustration of this process is shown in Appendix 1[22]. It can be seen that this process is based upon algorithms taken from previous designs, therefore these algorithms cannot be applied, with a similar degree of confidence, to ships where either the hullform or payload is such that it deviates by a significant amount from the ship from which the sizing algorithms are derived. It is necessary to use judgement and allow margins of uncertainty on any items about which there is doubt over the validity of the scaling algorithms derived. The method of balancing space and weight is valid, but without confidence in the algorithms used to size parts of the ship confidence in the results is low.

Research has been carried out at UCL into a computer aided suite that will allow designers to layout ships using functional compartment blocks and in this way obtain feasible solutions [Andrews 81], [Andrews 84a], [Andrews 86], [Andrews 87]. Such a system was subsequently produced for the MOD for submarine design and resulted

[20] The use of previous design data results in a situation where novel design layouts cannot be scaled. Standard layouts can be scaled as there is a basis about which scaling algorithms can be derived with some confidence [Bayliss et al. 96], [UCL 97].

[21] Whilst it is possible to size a ship purely on this numerical basis no naval architect would conduct this analysis in isolation. In creating preliminary designs it is important not only to ensure the space and weight balance is achieved but also to demonstrate the feasibility of the design as a whole. This requires parallel development of layout, and modification to ship hull parameters, whilst the numerical sizing is still being undertaken [Van Griethuysen 94].

[22] Appendix 1 details the UCL B.Eng. warship design procedure [UCL 94]. This is a simplified version of the numerical sizing process. A computer system (CONDES) has been developed to implement this process, allowing the use of confidential ship data, for the MOD [Hyde & Andrews 92].

in a practical design system, SUBCON [Andrews et al. 96]. This methodology was further developed at UCL [Dicks 98], [Dicks 00], resulting in a Building Block Methodology for surface ship design, the implementation of this methodology being termed SURFCON. This name has recently been used to designate the UCL sponsored Building Block capable module in GRC's Paramarine computer aided ship design system [Andrews & Pawling 03], [GRC 03]. The novel approach to the design process uses the concept of manipulating, graphically, a series of functional building blocks. These blocks have associated characteristics that allow for analysis to be carried out on the design as it progresses. An overview of the methodology is given in the following subsection[23]. The research detailed in this thesis has been developed in conjunction with this work by Dicks [Dicks 00]. Whilst the Building Block Methodology allows the designer to develop an initial warship design, there are no specific elements to allow generation of feasible topside arrangements beyond just location of superstructure and topside equipment. The Building Block Methodology concentrates on the generation of the internal arrangement and the resulting hullform. The research detailed in this thesis details a methodology that could be implemented in conjunction with the Building Block Methodology to provide an overall warship concept design tool [Bayliss 97], [Andrews & Bayliss 98].

2.3.1. SURFCON Methodology

The surface ship Building Block Methodology is directly descended from the submarine methodology detailed by [Andrews et al. 96] and has been placed in overall warship design methodology context by [Andrews 98]. The method can be considered as comprising the six stages outlined below and illustrated in Figure 2.4.

1. An outline requirement is identified and a design style proposed.
2. Drawing on novel or historical data a series of building blocks are defined. Each building block contains geometric and technical attributes regarding the functions of that block.

[23] This subsection is derived from [Dicks 98] which gives a technical overview of the research demonstration of a surface ship preliminary design system, based on the researched Building Block Methodology, termed SURFCON.

3. A design space is generated and building blocks configured as required within the design space.
4. Overall balance and performance of the design are investigated using simple and flexible algorithms and, if necessary, analysis programs external to the main system.
5. The configuration is then manipulated until the designer is satisfied.
6. Decomposition of the building blocks to greater levels of detail is undertaken, as necessary to increase confidence in the design solution.

Image removed due to third party copyright

Figure 2.4 : Overall Features of the Building Block Methodology [Andrews & Dicks 97]

As with many design methodologies the focus lies with design decisions, one of the key systems aims being to present sufficient information to the designer to allow these decisions to be well informed. Furthermore, the inclusion of a graphical computer interface means that the results of decisions are easily visible, affecting all characteristics of the design rather than simply those that are mathematically amenable. This avoids the problems inherent in numerical synthesis methods where numerically balanced ship descriptions are found to not necessarily be valid ship designs when the configuration and functional descriptions are subsequently produced and when subsequently important aspects, not in the initial weight/volume synthesis, become apparent downstream [Dicks 00].

Early in the design data may be scarce. Consequently initial decisions have to be confirmed as the design progresses. Furthermore, SURFCON must include the capability for design representation to increase in detail as a design evolves. The Building Block design stages are shown in Table 2.1 [Dicks 98].

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Table 2.1 : Surface Ship Design Stages [Dicks 98]

Design preparation involves:-

- The collection of data and the organisation of this into functional groupings. Thus it will not only be necessary to define required functions but also the spaces required to fulfil these functions.
- Some aspects of design 'style', i.e. superstructure philosophy, number of passing decks.

The major feature design stage is used to determine the minimum dimensions meeting the requirements of the design generator, and it forms the starting point for the Building Block iterations. The multiple Building Block design stages start at a crude level of design definition with the ship modelled as a small number of Super Building Blocks (typically 15-20 for a frigate/destroyer design). In subsequent iterations these are decomposed to form a larger number of Building Blocks as the design representation increases in detail (approximately 150-200). In the general arrangement stage the functional Building Blocks are replaced by the spatial elements of the ship, i.e. compartments and spaces. Here the final arrangement of the preliminary design is prepared and the dimensions and characteristics of the balanced ship design derived [Dicks 98], [Andrews & Pawling 03].

2.4. Topside Design

The topside environment can be considered as encompassing all that which is placed on the weatherdeck of a warship. This is not only items of equipment but also structure. Although the superstructure of a ship is designed to contain specific internal spaces for equipment or operational rooms, placing it on the weatherdeck of the ship results in it interacting with the rest of the topside environment. In addition to the superstructure there are other large items that are necessary on the weatherdeck of a ship that can be considered part of the ship's overall infrastructure. Exhausts and air intakes are required and their placement is usually dictated by internal arrangement within the hull. A generic list of the major equipment items for a frigate/destroyer and a topside design checklist is given by Broadbent [Broadbent 96] and is reproduced here as Appendix 2.

Investigation into topside design methodologies currently used during preliminary design, plus the research at UCL into Building Block Methodologies [Andrews & Dicks 97], [Dicks 98], [Dicks 00] has identified a requirement for topside design to be considered much earlier in the design process. One justification for this is the fact that ship length, particularly for frigates, is often driven by the topside layout, rather than length emerging from a numerical sizing of the spaces needing to be housed in the hull (Figure 2.5) [Brown 87].

Although the traditional approaches do not just employ numerical sizing, and should consider topside layout as part of the parametric survey [Van Griethuysen 94], an improved method of accessing topside interaction implications throughout the design process would aid the naval architect in their task of producing viable designs to whatever level of detail is required at the particular design stage. With modern weapon and sensor equipment there is a requirement to provide adequate arcs of coverage for all equipment and sufficient separation to allow their correct operation [Gates 87]. The space requirement for a helicopter landing area and hanger is usually a significant feature and can take up one third or more of the length of the ship [Brown 87].

Image removed due to third party copyright

Figure 2.5 : Critical Dimensions Affecting Topside Layout [Brown 87]

Warship roles are varied and the designs that result from these differing roles are also varied in both overall size and design configuration. The final solution is often dominated by a design driver [Andews 93], [Broadbent 96][24] that is considered to be the most important factor for a particular ship. In some cases the design driver is obvious, such as the flight deck and hangar arrangement on an aircraft carrier [Chapman 60], [St Denis 66], [Eddison & Groom 97], [Menon & Scheele 97], [Webb et al. 97]. For frigate and destroyers the design driver is often the requirement for a minimal overall length to provide sufficient separation between the different equipment items required [Purvis 74]. The nature of the problem is highlighted in the description of the NFR90 design [Schaffer & Kloehn 91] where the length of 133m is a direct result of the spacing required on the topside. Similar influence of the

[24] Broadbent refers to the design drivers as Macro Drivers.

topside length requirement can be seen in the progression of the Type 23 Frigate design from 100m to 123m in length as additional capabilities and then further topside equipment requirements were added post Falklands [Bryson 84], [Thomas & Easton 91]. For other ships the design driver may not be directly topside related, for example an Amphibious Assault Ship where the requirement is to store, transport and deploy military vehicles. This requirement impacts on the available topside space and depending upon the arrangement of the internal and deployment spaces can place constraints on the available topside space and available positions for equipment [Ferreiro & Autret 95], [Downs & Ellis 97].

The topside configurations of different ships differ depending upon the role of the ship and the design philosophy behind the ship. For differing roles the designs are often driven by the equipment required to carry out the role, however, for the same role, different solutions can be developed, all of which meet the demands, to some degree, placed upon them. Although the designs are often dominated by a few major equipment items, minor items (in ship fit terms) cannot be ignored as they may be crucial to a given operation (e.g. HF communications, boat arrangements) and must be placed into the topside environment in areas where they will operate correctly.

This thesis presents research that has been undertaken to investigate the issues that are significant in the topside design of all forms of naval surface ship. The end result of this research is a companion system to the proposed implementation of the Building Block Methodology for compartment layout, SURFCON [Dicks 98], [Dicks 00]. Figure 2.6 shows that the two suites are not intended to be used separately but will together form an overall concept design process [Bayliss 97], [Andrews & Bayliss 98]. This will take the initial role outline and allow the designer to produce designs, making use of the methodologies contained within the proposed overall suite. There will have to be interaction between the two systems because decisions made in either may have an effect on the other. The eventual aim would be to integrate the suites to such an extent that they form one single system providing the critical design tools in a seamless ship design environment.

[redacted]

Figure 2.6 : Proposed Systems Interaction [Bayliss 97]

2.4.1. Topside Equipment

The topside environment of a naval vessel can be considered more complex than a commercial vessel. This is due to the large amount of different equipment that has to be placed into this limited space. Although it could be argued that some merchant ships are complex, for example FPSO's (Floating Production Storage and Offloading Systems), these ships are very specific in application and do not have the wide variety of different types of equipment seen on a warship. The following brief descriptions outline the major types of equipment that need to be included in a typical warship topside. Appendix 2, largely taken from Broadbent [Broadbent 96], contains a more detailed breakdown but all items fall within one of the following major equipment groups. Appendix 3[25] reviews the topside arrangement of some current naval ship designs and the impact that weapon systems, aircraft and signature reduction measures have on the overall topside arrangement.

[25] The discussion contained in Appendix 3 provides background to the topside equipment items and integration issues discussed in the main text.

Weapons

The weapons of a warship form a major part of the topside equipment and fall into two categories. Offensive weapons are those used to attack targets, and these may be air, surface or underwater targets. These offensive weapons are often missile based, requiring storage and launchers. Large guns are also used for this offensive role. Defensive weapons are used to defend the ship when under attack from missiles/aircraft and are missile or gun based.

Radar

A naval ship will have a number of different radars, including a navigation radar as would be seen on a commercial ship. In addition to this radar there is a requirement for search radars, and depending upon the role these can be for surface or air search, or both. Further radars will be required as part of the weapon targeting systems, often two trackers are required to control a weapon system to provide full coverage. The development of the multi-function phased array radar means that future ship designs may have these differing radars replaced by a larger multi-function radar handling several tasks at once [Janes 01].

Communications

Due to the operating environment that naval ships are designed for, coverage of the full spectrum of communication frequencies can be required. This requires a large number of transmitting and receiving antennae with the required number increasing as the complexity of the ships communication system has increased. The number of antennae on a US aircraft carrier increased from less than 40 in 1950 to over 160 in 1974 [Reuter et al. 79]. In order to transmit at low frequency these antennae are large, often 30m in length [Law 83], [Gates 87] and have to be incorporated into the overall design. These long antennae are often strung between two masts but this has the requirement for a separation between masts of at least 30m with nothing between the masts that would become obstructed by the presence of the cables (e.g. vertical launch missile silos). In addition to these communication antennae, antennae are required for satellite communication and to receive

Global Positioning System (GPS) data. The development of deck mounted antennae and the Integrated Technology Mast (ITM) [Treen & Alger 00] where several sensors can be incorporated into a single structure may reduce the ship integration demands.

As warfare technology improves, inter-ship communication enabling a co-operative engagement capability (CEC) will increase this communication requirement [MIT 96]. This capability enables the combat systems of the ships operating in the same battle group to be linked, hence each ship has the complete combat system information fed to it from other ships. Whilst greatly enhancing the warfighting capability of the battle group this places a large communication burden on all of the ships involved as large amount of data need to be transmitted and received.

Aircraft

Where possible, depending upon the size of the ship, naval vessels are equipped to carry aircraft. In most cases helicopters are used, with larger fixed wing aircraft only being deployed on purpose built aircraft carriers. The ship may just have the capability to land the helicopter or may have full support capabilities, including the flight deck, full hangar (as opposed to just a shelter), refuelling, stores and maintenance facilities, termed an organic capability.

Ship Sensors

In addition to radars, a warship is equipped with a variety of sensors that enable it to operate. The bridge must be located in a position where the ship crew can safely operate the ship, good visibility is essential. Additional electro-optic[26] sensors can be used to aid the ship crew and these must be placed in suitable positions, where clear sight and the safety of the operator can be ensured. Further sensors such as towed array sonars need to be located

[26] These are optical systems which are enhanced through the use of electronic methods to enable the operator to improve vision. This may be through magnification, use of infrared vision systems for night sight or other video techniques.

in suitable positions. This most often creates the requirement for an open quarter deck [Janes 01] but different equipment types may impact on the topside arrangement to a greater extent.

Electronic Warfare

Further electronic equipment is required in order to process electronic warfare[27] data. This can be data received from transmitters on other ships, missiles and aircraft. These transmitters include jammers used to confuse radars with spurious signals. The EW suite comprises ESM equipment for detection and, often, the ship's own ECM active jammers. Additionally, decoy systems are deployed off-board to confuse incoming missiles (often being deployed in conjunction with jammers on the ship). Additional decoys may be deployed to confuse incoming torpedoes and may be integrated with the EW suite.

Ship Operating Equipment

A large amount of equipment is required in order to operate a ship safely. Some of this can also be found on commercial shipping, such as sea boats[28], anchoring arrangements, and cable handling. However there is normally a greater requirement for a naval vessel to operate without direct shore support for an extended period of time and this results in further equipment such as replenishment at sea stations and equipment, so that the ship can be re-fuelled and re-stored whilst at sea.

Safety Equipment

Safety equipment is required onboard, and a large proportion of this has to be located on the topside, lifesaving devices must be provided in areas that allow correct deployment.

[27] Electronic warfare is a term used to describe methods of electronic detection and countermeasures. An offensive or defensive tactic using electronic systems and reflectors to impair the effectiveness of enemy guidance, surveillance or navigational equipment which depend upon electromagnetic signals [Chambers 91].

[28] Due to the naval role of the vessel, equipment such as the sea boats will be used for a number of different activities, such as policing duties.

In addition to these specific equipment items, there are also other important factors that have to be included. Provision must be made for access and maintenance, most of the topside equipment will need to be maintained by the ship's crew and safe access is vital. For some items this access may only be required to allow cleaning and painting, for other more complex systems the system maintainer will require access for himself and his test/repair equipment. An additional complication is that some of the equipment emits radio frequencies damaging to health and so there is a need for exclusion zones and personnel free areas [Gates 87], [BR8537 90]. The top of the bridge is often a personnel free zone whilst equipment is operating, this is due to the large number of emitters on the masts. Other areas on the ships have restricted access to ensure that personnel are not exposed to hazards for longer than is safe.

2.4.2. Topside Integration

The aspect of topside integration is complex involving many different engineering disciplines, ranging from the complex fields of electromagnetic interference and computational fluid dynamic (CFD) prediction of topside air flow to analytically simpler areas such as RAS philosophy and lifesaving arrangements[29]. It is not possible to be an expert in all of these disciplines and no one person can carry out a total ship topside design[30]. At the early stages of design it is necessary to carry out many quick design studies into many different forms of ship that may meet an envisaged role. It is most likely that these studies will be carried out by a small team consisting mainly of naval architects but aided by input from experts in differing fields, such as combat system design. The aim of this research is to propose methods by which the naval architect can be aided in this task without having to co-ordinate the input from a large number of expert teams early in the design stage where the information required by the experts is unlikely to be fully defined.

Methods currently exist [Van Brunt 86], [Juras & Cebulski 92] that are intended to help the naval architect approach the problem of topside integration, however these

[29] Further information is provided later in the text when these subject areas are introduced and discussed in detail.

[30] Tibbets and Keane present an argument that it is not possible for a single person to carry out design, rather that design is everybody's job [Tibbets & Keane 95].

methods are largely processes by which the topside elements are given some form of priority, narrowing the problem to individual item placement and possibly masking problems that exist between equipment. The shortfall in many of the processes is that the analysis of the design is carried out downstream of determination of the main topside arrangement, this is a symptom of the tools available for analysis of topside arrangements. Any specialist tools that exist have been developed by the individual disciplines concerned and as such are often far too complex, and require too much detail, to be applicable in the early stages of topside definition. As a result the topside design process is essentially a sequential one with iteration only available once a large amount of work has been carried out in order to reach the level of definition required by the analysis tools.

The research reported in this thesis shows that it is possible to assess topside arrangement at a far simpler level than these complex tools require and this early assessment is what is required for the early stages of a design. The output from these simple tools is not of the accuracy obtained from the specialist tools but it can be obtained quickly and easily, requiring little specialist knowledge or computing facilities. Whilst not being of a level of accuracy commensurate with the downstream specialist analytical tools it does provide guidance as to whether a solution is feasible or whether one arrangement is better than another. It is considered that a system containing simple tools such as these, combined with simple rules of thumb, design guidance and knowledge based systems will allow the naval architect to have far more confidence in the topside arrangement that is proposed and therefore be more confident about the total ship solution.

The importance of topside integration is not new, it has been a major influence on the topside design of warships and has had to evolve as the warships have evolved [Eckhart 69], [Tibbets & Baron 99]. The elements that have to be placed on the topside of a warship are large in number and diverse in operation and requirements. In 1969 Eckhart noted this in stating that a limit would be set on the growth of warship capabilities due to their electromagnetic effectiveness [Eckhart 69]. This problem was foreseen ahead of the large increase in electronic systems experienced in modern warships together with the increased power demanded by the new equipment, particularly in the electronic warfare (EW) area, that is the driver in integrating these systems into the topside arrangement of warships [Lemley 96]. Clearly the problem of integration is a complex and growing one, even a small offshore patrol craft or a lightly armed warship contains a large amount of complex weapon electronics, sensors and armament [Cunningham 82]. The impact of weapon systems and electronics on surface warship design are discussed by Gates and Rusling [Gates & Rusling 82] who describe the impact that weapon systems have on warship design, as well as describing some techniques aimed at simplifying installation of electronics and weapon systems, such as cellularity[31] and modularity[32] [Gates 85], [Gates 87].

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Figure 2.7 : Typical Topside Equipment [Calvano et al. 94]

Figure 2.7 shows some of the major equipment items that have to be located on the topside of a warship. The figure is taken from an American postgraduate design study for a Regional Deterrence Ship for the year 2010 and hence details US Navy systems [Calvano et al. 94], [Calvano & Riedel 96]. The items of equipment considered consist not only of the necessary weapon equipment, but also the associated trackers and radars, as well as communications equipment for all frequencies of operation and illustrates the large number of items that need to be accommodated. Those items shown indicate a complex arrangement but do not

[31] Cellularity involves two concepts, a transport envelope, which specifies good access to the compartments, and an installation envelope which addresses the width and height requirements [Gates 85].

[32] Modularity refers to systems where the design and construction of the ship is simplified by use of a modularised/containerised build system [Gates 87].

include many of the smaller non combat system items that also require placement, further complicating the design.

2.4.3. Topside Conflict Areas

The major source of conflict on the topside of a warship is the interaction between systems and equipment. Below is listed the major equipment and associated activities that have to be considered. In addition to these, structure, exhausts, access for stowage, seakeeping, seamanship and ship handling must be considered.

- Combat system elements (antennae, communications, weapons)
- EMC/EMI/RADHAZ
- Radar Cross Section and Infrared signatures
- Replenishment at Sea (RAS)
- Boats
- Access and NBCD requirements
- Aircraft, decoys and towed bodies

Each of these aspects needs to be placed and consideration must be given to the interaction and impact each will have on the other. Although it may be possible to place some systems in optimum[33] positions the interaction effects between different systems are only analysed very late in the design process. Consideration is given to any possible interaction but this has to be based on expert advice and past practice at the point that the location choice is made.

2.4.4. Current Topside Design Philosophy

At present the majority of topside design work is carried out downstream of the initial concept work. This may result in unforeseen problems being identified too late in the design process to allow the fundamental changes to the design that may be required without major disruption. The goal of the topside designer is to maximise

[33] An individual equipment item may be placed in what is considered, in the equipment designer's opinion, an optimum position. This is a position where, for the particular item in question, all of its requirements are met. These requirements may include available field of view and access arrangements. In deciding this optimum position no consideration is given to interaction with other equipment items, the equipment item is positioned to ensure best individual performance.

overall ship performance in meeting mission requirements. This is accomplished by teams of naval architects, marine engineers and combat system engineers working together. Emphasis is placed on locating primary mission related elements, followed by ship self defence, communications, navigation and other systems. Ship constraints include superstructure, intake and uptakes spaces, cranes and boats, flight deck operating envelopes, competing weapons and sensors, mast height restrictions, green water capability, ship motions etc. After placing the various ship topside elements their individual performance and that of the whole ship can be assessed and the design iterated. An outline design process as published by the US Navy, but similar to the approach used in the UK, is detailed below and illustrated in Figure 2.8 [Juras & Cebulski 92].

1. Review mission requirements and design constraints
2. Select topside elements
3. Layout ship model
4. Place topside elements on ship
5. Assess performance
6. Prepare drawings

Image removed due to third party copyright

Figure 2.8 : Outline Topside Design Process [Juras & Cebulski 92]

Although showing an iterative path, this is, apart from expert advice provided during the process, essentially a sequential process as the assessment of performance is downstream of the design and layout process and it is only at this stage that any evaluation and iteration occurs. This results in a large amount of layout work being carried out before a full evaluation. Only then may an early design decision be found to severely limit the design, resulting in work after that point being wasted. There is no fixed universal process and a different, more detailed, approach is illustrated in Figure 2.9 [Van Brunt 86].

Figure 2.9 : Detailed Topside Design Process [Van Brunt 86]

Iterative paths are shown, but again they are only fully applicable once a large amount of definition has been carried out. The later stages of the process, such as physical brass modelling[34], would only be carried out further into the design process than the preliminary stages of design that this research is focused on.

2.4.5. Topside Integration Problems

The previous section outlined a sequential process with corrective action only being possible late in the design process after detailed analysis. It can be seen that there are several problems with this method due to its sequential nature. The in-depth assessment of the topside elements is not carried out until the ship description is sufficiently detailed. Ideally all systems and the layout aspects should be considered concurrently during the initial phase. This would allow for all the interactions and quick analysis of the performance of different layouts to be made. An additional problem is the diversity of the elements to be placed. At present the layout is determined using previous experience and judgement, which does not allow for

[34] A technique where the design is modelled in brass, at reduced scale, and then analysed on physical electromagnetic ranges to measure interactions and radar cross section [Turner 97].

detailed knowledge of system interactions. Experts exist in all of the fields that need to be considered but they are generally only knowledgeable on their own equipment or technology. As a result the conflicts between systems or technologies are often unknown or simply not considered at the preliminary design stage. An expert on weapons will know the best layout and implications of changes on the systems with which they are concerned, however they will not necessarily know of the interaction that their system will have on the placing of all other topside components and all the general ship operational issues. Conflicts are only identified once the downstream general arrangement approval process is underway and the normal discrete analysis tools are only used once a firm topside arrangement is available making changes difficult, with the consequence that often the best arrangement achievable is the one resulting in minimisation of disruption.

The final configuration of the topside will inevitably be a trade off between many conflicting priorities. It is important for new designs to start with a clean sheet when building up the topside arrangement. Experience in topside design has evolved from monohull design and has limited applicability to the more versatile arrangements available when considering more novel hullforms such as the SWATH [Betts et al. 87], [RINA 88], Trimaran [Pattison & Zhang 94], [Zhang 97][35]. and hybrid ships[36] such as the HYSWAS[37] [Meyer & King 76], [Meyer 95], [Rice et al. 99]. Tools exist and design guidance is available on most of the items of equipment requiring placement, the problem is arranging the elements when it is difficult to maintain an overall picture of the totality of the topside design. This is compounded for unconventional hullforms where past design experience and judgement do not necessarily hold true. This is shown in some recent concept design studies where the topside layout cannot rely on past sources of information as they do not exist. Alder

[35] Studies into the applicability of the Trimaran hullform have resulted in a large research programme involving University College London and the UK Ministry of Defence most notably documented in [Andrews & Hall 95], [Andrews & Zhang 95a], [Andrews & Zhang 95b], [Summers & Eddison 95], [Andrews & Zhang 96], [Bayliss et al. 96], [Andrews & Bayliss 97], [Bayliss et al. 98a], [Bayliss et al. 98b].

[36] A Hybrid Marine Interface Vehicle (hybrid ship) is one that relies on more than one source of sustention (or lift) simultaneously over a major portion of it's operational speed envelope [Meyer 95].

[37] HYSWAS – Hydrofoil, Small Waterplane Area Single Strut. Essentially a single cylindrical hull located below the water linked via a vertical strut to the main body. Buoyancy is provided partially by the submerged hull and partially, at speed, by the foils when the main body is clear of the water.

placed two large helicopter hangers onto a Trimaran design as this was possible due to the extra beam [Alder 97]. Smith utilised the flexibility of the Trimaran arrangement to mount one prime mover in the superstructure. This resulted in previously unseen topside conflicts [Smith 96]. The benefits of the novel arrangements can be exploited but reliance on earlier design experience is not possible.

2.5. Computer Based Design Systems

An effective way to implement a methodology such as that proposed is to use a computer to store and manipulate the data. This subsection details systems that have been developed in the field of ship design. Some whole ship and topside design tools are introduced. Possible shortcomings and differences in these approaches compared to that proposed by this work are discussed.

The use of computer systems and more importantly the use of graphical design tools has increased rapidly [Andrews 84b] and continues to do so [Hansen 97]. This is due to the level of computing power that is now available at an affordable price. The increased use of computers in design work is most notable in the later stages of design where full 3D product models are defined which include not only the 3D geometry but also associative parametric relationships linking dimensions and objects, and non-geometric information [Baum & Ramakrishnan 97]. These systems are used to reduce the design, build and operating costs, improve quality and shorten the design and build cycles through the application of concurrent engineering. This is made possible by integration of 3D geometric information with a relational database product manager. The 3D models can be used not only for direct design purposes [Tan & Bligh 98], [Tinsley 02] but also to allow input from the end user at a stage where alterations can be made. Simulations allowing the end user to 'try out' various aspect of the design are increasingly used [Jons 94], [Miller et al 96] and are illustrated by the US Navy's Sealift Program where simulation of driving the vehicles into and out of the ship resulted in major problems being identified, yet requiring minor design work to solve [Edinberg et al 96]. Further simulation based design has been used to assess vehicle deck arrangements [Jons et al. 94], naval airships [Jons & Schaffer 95] and human factors implications [Woodrow et al. 98]. The future for such technologies has been investigated as part of a program sponsored by the US DOD Advanced Research Projects Agency and resulted in discussion and demonstration of the so called 'virtual shipyard' allowing the complete definition of the design within the computer and the use of information exchange and the Internet to enable concurrent design [Polini et al 97].

More specific general arrangement tools for warships have been produced in the US for design work into warships such as the General Arrangement Design System (GADS) [Carlson & Fireman 87]. Systems such as GADS use the power of computing to aid in the preparation of general arrangements. The objective is reduced time to develop a general arrangement, while at the same time eliminating data inconsistency and providing a rational general arrangement tool applying standardisation and automation in applicable areas. The shortcoming of such systems in the context of this research is that they simply computerise the available methods. There is no improvement in the methods underlying the process. The aim of both the research reported here and the associated Building Block Methodology [Dicks 00] is to provide a new methodology for preliminary ship design, not to computerise the old methodology.

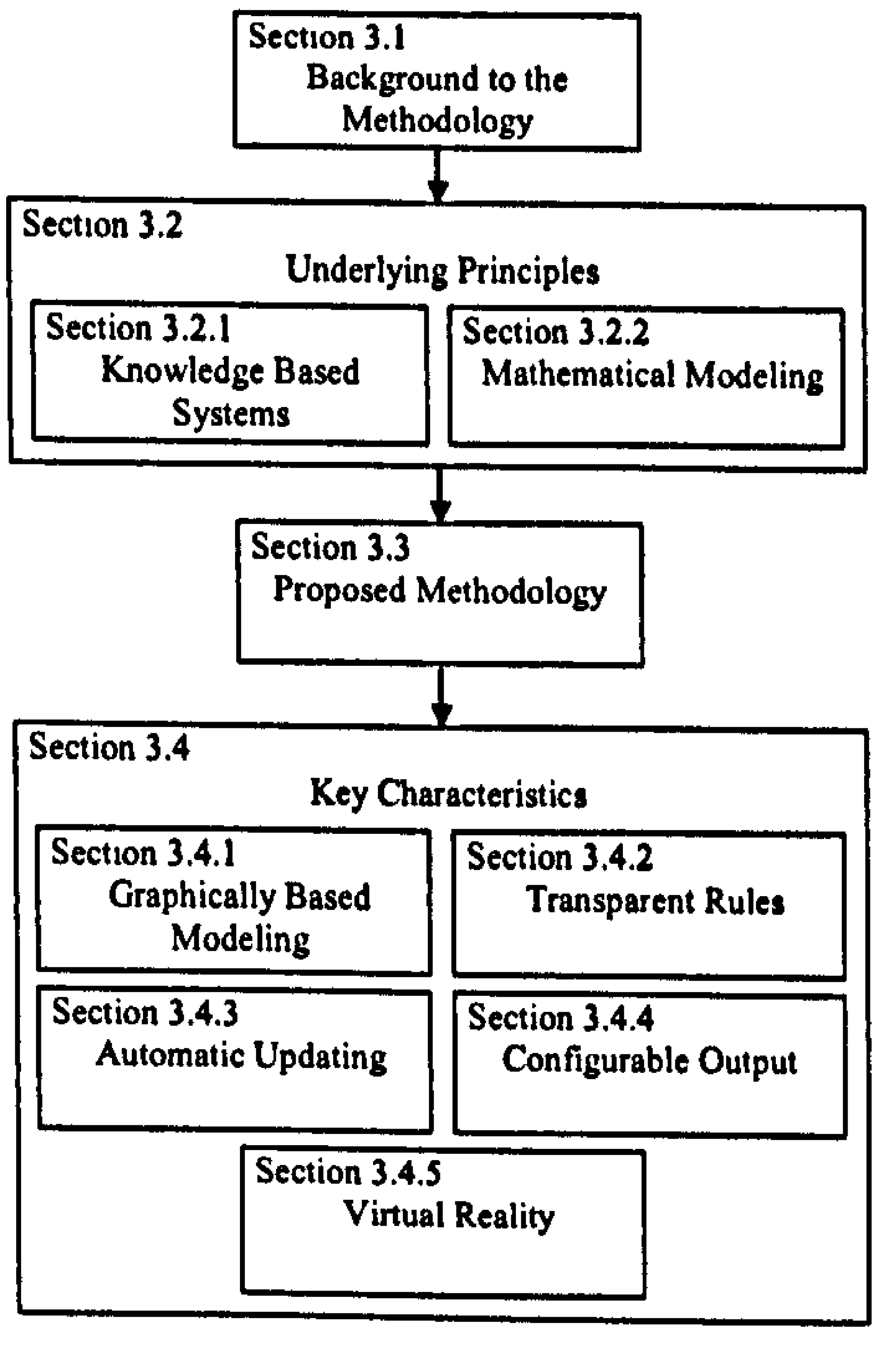
The US computer based Topside Design Model (TDM) allows for interactive design in a graphical model and provides an indication of optical coverage[38], line of sight radar detection[39] and antennae range prediction[40] [Law et al. 87]. This is an example of a system that is more than a simple drawing and visualisation tool, however it still relies on complex analysis requiring equipment and technology expertise and is limited in the type of design conflicts that are considered to those detailed above. It is a method of bringing together some of the existing codes into a more usable system. It is not an integrated topside tool as no emphasis is placed on aspects of topside

[38] Optical coverage refers to the area around the ship that it is possible to see from a given position.
[39] Line of sight radar detection refers to simple calculations using straight line geometry to determine the area that a radar is able to see. In practice, because of diffraction of the radar beams, this represents a pessimistic view of the blockage or 'wooding' as it is sometimes known. For the purposes of topside arrangement the use of geometric line of sight is traditionally accepted as a pragmatic assumption.
[40] Antenna range prediction is the calculation of the effective range of operation for an antenna.

design other than those that are weapon and antennae related. This topic of accommodating antennae systems in the ship design process is one that has been tackled many times but often as a separate design task to the design of the rest of the ship topside [Law 79]. A combined total topside approach is proposed by the US Naval Sea Systems Command [Baron & Newcomb 97], it highlights the need, rationale and vision for the integrated topside design requirement. This system is focused on more detailed stages of ship design and as such include tools where detailed information is required. The lack of development of tools for the early stages of design highlights the gap in current topside design techniques.

The use of knowledge based systems both in general naval architecture and in more specific areas of ship design has been investigated many times. Attempts have been made to capture the expertise of ship designers in a numerical way that can be applied to new ship designs [Biran & Kantorowitz 86], [Duffy & MacCullum 89], [Van Hees 92], [Carling 93]. The development of a modularised artificial intelligence (AI) system to improve the design of electromagnetic systems and compatibility issues has also been undertaken [Zhou et al. 89], and allows the interrogation of existing databases and model results. There is recognition that a simple 'off the shelf' system is not applicable for the complex tasks involved in ship design using expert databases, spatial reasoning, model base management, track based reasoning and analytic reasoning. Zhou considered it necessary to develop a specific system tailored to the problem and the results from such an attempt are described in the reference [Zhou et al. 89] along with the large amounts of further work required for a fully workable system. Zhou's tool is a specific tool requiring knowledge of the systems to be used and the type of environment they are to be used in. Although claiming to provide an AI facility as well as an expert database, the system could not be used by a designer unfamiliar with electromagnetic design and it does not easily integrate with other topside design issues of interest to the total ship design.

3. CONCEPTUAL METHODOLOGY AND DESIGN PROCESS



3.1. Background to the Methodology

The aim of this research is to produce a tool that can be used by the preliminary ship design team. This tool is to be used at the initial stage of design to assess different topside layouts and the implications that different systems will have on ship operability. The designer must be able to investigate many differing solutions both in system choice and ship layout making informed decisions as to the different impacts the solutions will have.

This chapter introduces the proposed methodology. Some background information is given which includes a definition of the topside environment as it is seen in the context of this work. This is followed by consideration of the underlying principles, both knowledge based systems and mathematical algorithms, relevant to any proposed system. The concepts behind the proposed methodology are given in Section 3.3, with Section 3.4 outlining the key characteristics required by any system implementing the methodology. No detail is given in this chapter on how the proposed methodology is to be implemented as this is described later, following an outline of the initial investigation into the applicable methods to highlight the requirements.

The task of designing a warship topside is complex and involves many different disciplines and the application of many design rules [Van Brunt 86], [Juras & Cebulski 92], [Tibbets & Baron 99]. The constraints placed upon the elements of a given ship design are not just those relating to weight and space, although important, but also those relating to complex interactions between equipment, ship structure and personnel. The complex interactive nature of the topside arrangement is illustrated in Figure 3.1 [Bayliss 97] and suggests there is not an obvious sequential process. This figure is not exhaustive but does highlight most of the topside equipment related issues. In addition to these, consideration must be given to other factors, such as seakeeping implications, structural continuity, access, uptake routing and downtake routing. It is necessary to consider interactions at all stages of the design and to be aware of the physical and geometric constraints. With current design tools there is no co-ordinated way of approaching the topside design of a naval vessel.

[redacted]

Figure 3.1 : Topside Design Environment [Bayliss 97]

3.2. Underlying Principles

This subsection introduces the concept of knowledge based systems and mathematical modelling. These are the two concepts that will form the basis of the proposed methodology.

3.2.1. Knowledge Based Systems

A knowledge based system, or expert system[41], is essentially a series of rules that can be applied to a given situation. It consists of knowledge provided by experts and is compiled in such a way as to enable interrogation of the system and application to

[41] An expert system can be defined as an intelligent computer program that utilises knowledge and inference procedures to solve problems [Welsh et al. 90].

new problems [Naylor 83], [Alty & Coombs 84], [Addis 85], [Slatter 87]. Symbolic processing is used where the information is processed as words rather than numeric data. It is not a self learning system in the way that neural networks could be considered to be [Lippmann 87] but more a collection of knowledge that can be applied to a given field. In this way one can envisage a system involving an intelligent database where the equipment to be utilised is analysed and the data stored. This database would hold all relevant details concerned with layout implications for the individual equipment. Intelligence within the database would allow underlying rules to be associated with individual equipment data. In this way it would be possible to interrogate the database on ship layout and combinations of systems. The database would hold this information together with the rules governing the placement of the systems in relation to others. This can be considered to be an expert system in that it is not working from a set of fundamental mathematical principles and formulae and there is not an absolute correct answer. However past knowledge of implementation and the skills of the existing specialists in areas such as EMI/EMC and layout would be captured and in effect allow the designer to utilise their knowledge as well as his own in making design choices.

A record of facts about known problems and interactions would be secondary to the knowledge base that would be built up through interrogation of existing experts and procedures. Data exists on current problems and solutions employed, however, this data is used in a remedial manner and the corrective action is taken only once the ship is in service. The collation of this data should allow the designer to check the proposed design solution against previous problems encountered. Two databases exist in the US, the Shipboard Management Information Tracking System (SMITS) and an unclassified version, the Shipboard Technical Assistance Network (STAN) [Juras & Cebulski 92]. These hold data on EMI/EMC compatibility problems that have been experienced by the US Navy and the appropriate steps taken to rectify them. Similar information is held in the UK but there is no unclassified version. If this information was held in an intelligent database which allowed interrogation then the task of the designer at the preliminary stage would be eased. The use of an expert based system would allow a transparent interrogation of the knowledge base and known problems. It could then signal possible conflict areas and suggest corrective measures.

3.2.2. Mathematical Modelling

Knowledge based systems are not the only approach that is applicable to the preliminary topside design layout process. Ship design invokes considerable mathematics, however mathematical modelling on its own is not sufficient to design a ship[42]. However when considering individual areas of concern, mathematical approaches to modelling may provide superior design guidance to that captured in a knowledge database. The mathematical approach, where applicable, allows for calculation to be carried out on the design in question, rather than drawing on knowledge of similar designs.

Within the context of the proposed methodology there are a number of areas where the application of mathematics may allow solutions to be reached. Examples are in the area of radar cross section (RCS) prediction and electro-magnetic interference (EMI). RCS depends upon the reflected rays from the object in question and hence can be seen to be a function of the underlying geometry of the object, in this case the ship and the electromagnetic propagation of the radar waves. Various methods exist to allow the prediction of RCS from the shape and layout of the ship, these are all mathematically based[43]. In a similar fashion there are underlying mathematical equations that govern the propagation and interaction between electromagnetic waves. Although actual design cases are very complex, simple models can be constructed for various layouts and the interactions predicted through mathematical means rather than a knowledge based approach.

[42] "Mathematics was introduced into design (rightly) but one of its side effects was the idea that mathematics and calculation could 'get it right'." Sir Rowland Baker as reported by Andrews [Andrew 81a]

[43] Expanded upon in Chapter 6, detailing the RCS modelling work.

3.3. Proposed Methodology

The complex nature of all the issues requiring consideration has been shown in Figure 3.1 and the proposed methodology caters for the interactive and non-sequential process. The underlying philosophy is the use of graphical representation linked, in a transparent manner, to additional data. The user will interact with a graphical element, whilst at all times retaining the data associated with that element. This underlying data can then be manipulated to provide additional design guidance.

The system will act as a repository for data about individual equipment items, and also about interactions. By manipulating the graphical representation, the user will allow underlying principles to be applied, being informed when design rules are broken. It is not necessary for the user to have knowledge about all the possible interactions and design rules as these are captured in the system.

The design space allows the designer to place items into space, and build up a picture of the proposed topside. The non-sequential process is catered for by allowing the user to activate only those analyses in which he is interested. The design space in not limited in any way, and the order in which items are placed is up to the designer.

Allowing the designer to activate an analysis at any point in the design process provides a flexibility that is not seen in current design methods. Any particular points of concern can be investigated, but the choice of what to investigate is always made by the user, not dictated by the system. The large amount of data held will not swamp the user with information as only those items in which there is concern need be highlighted. The system will capture all of the items placed and any possible problems that result, this will provide a checklist for the user serving as a prompt to ensure all required items are placed.

The open nature of such a system allows for further analysis methods to be incorporated as they develop. The underlying philosophy is the capturing of data and its graphical representation. Any tool that could analyse a particular requirement can be invoked to draw on the information held by the system to undertake analysis if required by the designer.

3.4. Key Characteristics

Several key characteristics are required of any system if the proposed methodology is to be correctly implemented. It is important that all of the following capabilities are realisable.

3.4.1. Graphics Based Modelling

The designer would use a graphically oriented interface to interact with the system. In this way the designer will be able to start with a bare topside model, be it for a monohull, Trimaran, SWATH or other naval vessel, and place elements into this design space. A full 3D model allows pre-defined items of equipment to be placed in positions both on decks and also up masts and at varying heights in-between. This system is not initially intended to be a full surface model which accurately represents specific items but may use simpler wireframe, surface or solid models to illustrate systems. This level of graphical representation instantly allows for physical interactions to be seen and avoided. Information for modelling of other interactions can then be combined with this model.

3.4.2. Transparent Rules

It is important that the user is informed by the system and not driven by it, the system must not provide a 'black box' solution. The user must have complete control over both the input and output of the system as well as the underlying formulae or assumptions. The knowledge base and mathematical modelling informs and advises, not dictates modifications. The user should not become involved in the details of interrogation of expert systems or use of mathematical principles. This should be a background operation with the user asking for specific information and the results either being graphically illustrated or concisely reported to the user.

3.4.3. Automatic Updating

The primary role for the proposed system will be the investigation of many varying designs. Therefore the user must have simple and fast methods for re-location of systems and modifications to layouts. The modelled interactions and changes resulting from any rearrangement should be instantly reflected in the output. In this way the user would always see the current, up to date, picture. A system where all component parts are first laid out and then subsequently analysed will not allow for the immediate flagging of problems and may result in wasted design time, as placing one item will have an influence on the others. Clearly the sooner the designer is informed of possible interaction problems the earlier the design issues can be addressed.

3.4.4. Configurable Output

The input and output is displayed in a graphical manner, configurable by the user. The vast quantity of information involved must not swamp the user. This data can be managed by the designer through use of a multi layered system where different layers can be turned on and off in order to illustrate different interactions. An example list follows which shows the different aspects to be highlighted.

- Weapon arcs / shock, blast and debris areas
- Radar and sensor coverage
- EMI/EMC
- RADHAZ
- RCS/IR
- RAS systems and access for stowing
- Boat and decoy operations
- Access for ship handling and navigation
- Firefighting, NBCD and escape
- Personnel movement
- Maintenance
- Equipment manning
- Aircraft operations

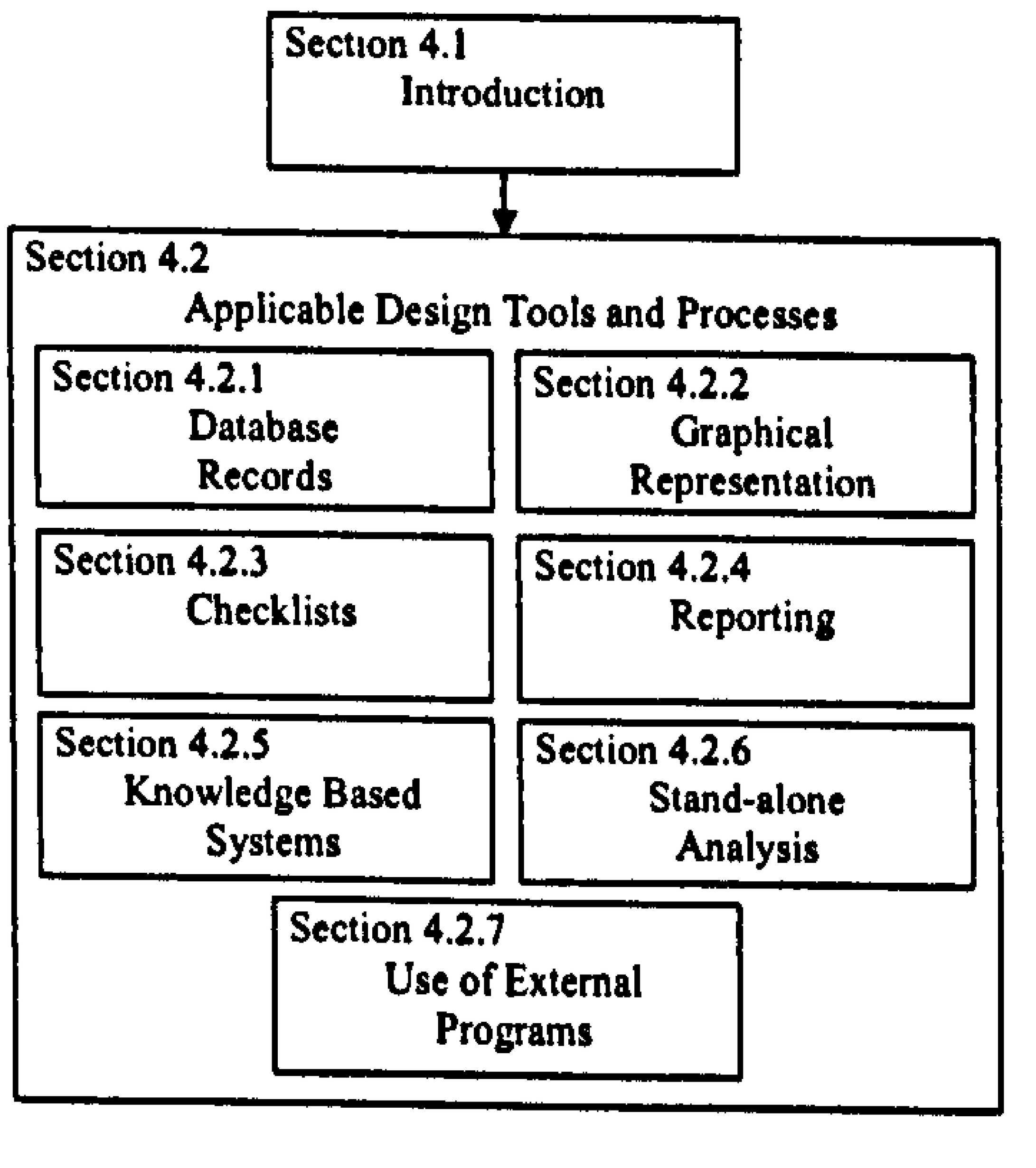
For these aspects the user could choose one or more of these modelled outputs and graphically display the interactions as an overlay to the 3D model held in the computer. Any conflicts between the siting of equipment are flagged up to the user to allow informed decisions to be made on relocation.

3.4.5. Virtual Reality

The use of virtual reality techniques[44] would allow the complete ship to be designed and constructed in a virtual world. This would allow the designer to enter into this virtual world through the use of visual headsets and other sensory devices and to 'walk' around the ship. The designer, or potential operators of the ship, could attempt to operate systems and would experience problems with interactions and clashes at first hand. With computing power in its current state this is a tantalising possibility with the technology to carry this out under development and available in the near future. Although virtual reality techniques are only proposed for future implementation once the technology matures it is currently possible to obtain more detailed output such as fly rounds using full rendered images with commercially available CAD software [Polini et al 97]. These rendered images and animations are a powerful visualisation tool both for the designer and for the staff that have to be convinced of the solution or be brought into the design dialogue. The system must be capable of interfacing with virtual reality software as it becomes available but initially must focus on the basics.

[44] Virtual Reality is a technology allowing the definition of a virtual design environment [Polini et al. 97]. This can be defined as an immersive, 3D world where users can freely move about and visualise and interact with objects that have been defined and collaborate with other users in a shared, virtual world [Jons 94].

4. APPLICABLE DESIGN TOOLS AND PROCESSES



4.1. Introduction

Underlying the proposed design tools, that combine to form the proposed total design environment, are a number of basic concepts. This chapter details the basic concepts that are available to implement specific design tools. Different methods and approaches are outlined and their advantages and possible shortfalls highlighted. This chapter does not discuss how the methods are to be used by the individual design tools, this is covered in detail when actual design tools are discussed. In the chapters that follow three major topside design areas are introduced: Electromagnetic Compatibility (Chapter 5), Stealth and Signature Control (Chapter 6) and Scenario Modelling (Chapter 7). Each of these is considered key to the implementation of the overall methodology. They are outlined and their implementation discussed with reference to the concepts that are introduced.

4.2. Applicable Design Tools and Processes

4.2.1. Database Records

The proposed system will need to capture a large quantity of data. Ideally the designer does not want to define the equipment items that are to be fitted, but to choose them from a database. This database will grow as more designs are undertaken using the system. The database should initially be populated with data covering the range of equipment items that are most likely to be fitted[45]. The user should be able to add to this any further equipment items that are not held in the database, or modify existing equipment currently held in the database.

A large range of different parameters will be required for each element, and for different types of element the data requirements will differ. For example, the information required on a missile system will be very different to that required for a basic superstructure block or sea boat.

[45] It would be necessary to populate the initial design database with information about current systems. Data is available through the Naval Engineering Standards [DEFSTAN 00] and other compiled databases [BAE 00], [QinetiQ 02].

This requirement for data storage can either be met by a standard commercially available database or by bespoke software written as part of the overall system and tailored to meet specific requirements. Although it would be possible to use bespoke software to store all of the information and to recall it when required from either datafiles or matrices of information held within the computer system, this would essentially be a database of individual records and so the standard database format would facilitate this and require less bespoke programming and maintenance. The information for each item of equipment can be held as individual records within the overall database. The data held as part of an equipment item record will differ depending upon the type of data required on the item in question. The overall database will allow all of this information to be stored and interrogated when required.

The requirement for the system is that not only are these parameters held within the system but that they are linked to the graphical representation for the particular item. The database record should be directly linked to a particular graphical item, essentially forming one complete record containing all of the information.

The advantage of using a standard database is a reduced programming and maintenance load. Current database packages are flexible in their application and allow storage and manipulation of most types of data. The design of the database may be constrained in format by the type of database package used but not in operability allowing information to be stored and interrogated.

4.2.2. Graphical Representation

The proposed system is graphically based and so the graphical representation and manipulation of the items is very important. It is necessary to define the item in three dimensions (3D) and allow for manipulation within a 3D design environment. It is necessary that this manipulation is straight forward to achieve and is as intuitive as possible. The user of the system, most likely a naval architect, will not necessarily be a CAD expert and as a result does not want complex CAD tasks to perform. It is assumed that the user of the system is technically competent in the use of computers. There is no need to be an expert user of the CAD system in order to manipulate the graphical interface as operations will be limited to those feasible within the design space. In this way the total functionality of the CAD system will be limited to those functions required by the user to carry out the design task. The full capabilities of the CAD system will only be required when defining a new equipment item, when full functionality will be required. These tasks would have to be carried out by an expert user of the system. This expert user would have full access to the CAD system allowing any new equipment items to be graphically defined. If during a design the operator required a piece of equipment that was not available from the database then this equipment item would have to be defined and added to the database. This task would require full CAD functionality and the expert user would be able to access this functionality and construct the graphical representation of the new equipment item from available data on the new system. Additional expert advice would be required to correctly populate the database associated with the new item.

The graphical capability of CAD systems has grown rapidly over the past ten years, what was once a two dimensional (2D) system is now fully three dimensional and no longer relies on wire frame representation [Autodesk 95], [Autodesk 97a]. Items can be represented as 3D solid shapes and manipulation carried out on the screen by dragging and dropping in fully rendered mode and in real time [Autodesk 97b], [Forrest 01], [Paramarine 02].

Commercially available CAD packages are based around a graphics kernel. The kernel is the part of the system that handles all of the graphical representations and manipulations required, it is essentially the graphics engine behind the user interface of the overall package [Autodesk 97], [Paramarine 02]. These kernels are available for further development and should be used to provide the graphics engine within the proposed system. The use of a commercial package would allow the majority of tasks to be carried out but the package would not be customised to the particular task. The requirement for an intuitive system requires that the user is not faced with standard CAD terminology but that the tasks he wishes to perform are straight forward and uncomplicated to apply.

The proposed system requires a database from which items can be chosen and placed within the design space. This graphical representation must then be placed into the required position. This is essentially an assembly modelling process and commercial packages have been developed to handle tasks similar to this in a manufacturing context. An example of such a package is Autodesk Mechanical Desktop [Autodesk 97b], which has been used to simulate the CAD capabilities for this thesis. Other packages exist and are used to build computer models of complete designs, ranging from small mechanical assemblies to complete engineering designs [Butler 95], [AMEC 96], [Pullin 02], [Pullin & Davis 02].

An important part of the graphical representation is the capturing of data about items other than pure geometry. As the main interface to the system is a graphical screen other information must be made available to the designer through this graphical medium. The geometry of an item is important for placement, but where applicable a graphical representation of other constraints will provide an immediate and obvious guide to the user. In some cases these constraints will be fixed, this will result in a clear cut-off boundary, in other cases the boundary may be fuzzy. These fuzzy boundaries will result from systems where there is gradual degradation of the systems as they become closer to other items[46]. In this case a set of graduated constraints can be applied, these could be colour coded from green for no degradation, through yellow for some degradation and red for severe degradation. The use of different layers will facilitate different constraints to be indicated as well as the geometry of the individual item. The user can have a choice of which information to show but the graphical representation will allow the constraint to be seen as an overlay to the design space.

To aid the designer, constraints can be placed upon the items to align them within the design space. The facility will be required within the system to allow either the user, or information within the item record, to constrain the item in relation to others. An example of a design aid constraint is one where an equipment item is constrained to lie on the deck. If the user knows that the system in question is to be placed onto the

[46] Offline analysis would have to be carried out to calculate system degradation where there is no clear cut-off boundary. The results from this analysis could then be included as a series of graduated degradation zones. An example of the type of tool required would be the First Option Electromagnetic Interference Tool (FEMIT) [QinetiQ 01] which allows the calculation of electromagnetic interference as the distance between the transmitter and the receiver changes.

weatherdeck the application of this constraint eliminates one degree of freedom and aids placement of the item within the design space. In a similar sense constraints can be applied to the other degrees of freedom, essentially restricting the available movement of the equipment item to practicable locations.

A further requirement of the graphics system is the capability to present the design in a manner that can be used for presentation purposes. The best method to do this is to allow for fully rendered animations to be made, along with still pictures of the ship. This will allow the designer to present the work in a way that is easily understandable.

CAD systems have advanced in capability to the point where a standard Personal Computer (PC) is capable of running systems that will meet the specifications required [Autodesk 97b], [Paramarine 02]. The advantage of such systems is that they rely on kernel technologies that essentially form the heart of the graphics system. These kernel graphics capabilities are then encompassed within the overall CAD package. A readily customisable user interface can be created, based on a graphics kernel, reducing the amount of programming and maintenance required.

4.2.3. Checklists

One of the most demanding and vital tasks in the early stages of design is maintaining control of the design as it evolves. The use of checklists as the design evolves allows for the current state of the design to be known. Within the system these checklists should be automatically maintained and updated as the design progresses. These checklist may arise from standard lists held within the system, or may be pre defined at the start of the project by the designer. By referring to these checklists it will become immediately obvious if all of the points are covered.

Pre-defined checklists will essentially provide design guidance, ensuring the designer is aware of various standard aspects that need to be considered in the design. The availability of a customisable checklist will allow the designer to maintain a check against aspects for which there may be particular concern. Once defined at the start of the project, the list can be recalled in its current state at any time in the design and modified if necessary. This removes a large amount of the routine design control tasks from the designer as the lists will already have been defined, enabling the designer to concentrate on the overall design. The important aspects do not become lost as the design evolves ensuring the overall picture is not obscured within the detail of the particular area that is being worked on.

4.2.4. Reporting

With all design tasks the recording of design progress is important so as to maintain a record of the design development as it progresses. As the information within the system will be held within database records and graphical representations of the items, as items are added to the design, and manipulated, the system will maintain a record and this information can be compared to checklists.

A reporting task can be automated from this database to reflect the current state of design. A series of standard reports will allow the user to generate required records with little additional work other than commenting upon design decisions where applicable.

4.2.5. Knowledge Based Systems

Knowledge based systems are systems that capture information based upon previous design knowledge or design guidance [Addis 85], [Slatter 87], [Van der Nat 99]. One of the benefits of the proposed system is the capturing of design guidance and information that may otherwise be unknown to the user. It is important that this information can be captured and held within the system allowing interrogation when required. This essentially forms a basic knowledge based element of the overall package. This information often applies to the design as a whole and as such cannot be attributed to individual equipment items. Such information cannot therefore be held as part of the main database records. It is information relating to how equipment items interact rather than how an individual equipment item behaves.

This information should be stored and automatically applied to the design, in a transparent manner, when applicable. The benefit of the computerised system will be that the user does not have to consider this design guidance information as a separate task. Whilst undertaking a design the naval architect may have to consult a large number of references covering a wide range of different topics. The design guidance contained is often simple but is always considered as a separate task requiring effort and knowledge from the designer. This information can be stored within the system and guidance can be constantly applied to the design as it evolves. If the guidance criteria are not met the designer is immediately informed and can make informed decisions about further action required.

A possible shortfall in the use of knowledge based systems is the so called 'black box' solution [Jones 70]. This is a where the reasons for the design decision are hidden from the user. Jones describes the 'black box' paradigm as an inexplicable creative leap. If this is the case the user does not remain an informed designer but is driven by factors that may be beyond his control or even his awareness. Importantly, these factors may be inapplicable to the particular design study [Pattison 94]. It is important that all systems contained with the proposed system are clearly accessible to the user. If recommendations are made then the knowledge-based system must not make a change but inform the user of a problem and report the reasons for the problem. The designer can then make informed decisions as to how to progress.

4.2.6. Stand-alone Analysis

For some tasks the graphical interface and underlying database will not provide the capabilities required for particular areas of investigation. Where this is the case stand-alone analysis programs are required. These programs are not totally stand-alone as they will pull any required data from the system, but will require to be run as separate programs and may require additional input and specialised output formats.

Stand-alone programs are required for the more complex areas of analysis where immediate updating and reflection within the graphical representation of the design is not possible. They should be accessed from the main design environment and should preferably have a short run time. All information should reflect the current design and the main design process should not be halted by time-consuming analysis.

The stand-alone programs will allow for more complex analysis to be carried out when required. This will enhance the capabilities of the system beyond that possible within the graphical input screen. Specific details of the types of stand-alone analysis suitable for inclusion are detailed in the following chapters where specific requirements are discussed.

4.2.7. Use of External Programs

It is recognised that despite the methodology requiring all data to remain current at all times and to be instantly updated, there is a requirement to run more time consuming analyses where particular areas of concern exist. In most cases this is where the current programs and tools used downstream in the design process may be applicable. The proposed system will not include external programs as part of the development but will make use of those programs that have already been developed for particular areas of analyses [Parkins et al. 96]. A large number of analysis programs have been developed to assess the performance of weapons, surface ship characteristics and warfare sensors. The following details have been derived from [Parkins et al. 96] to illustrate the type of detailed analysis tools that are available[47].

- Weapons

  Modelling of both hardkill[48] and softkill[49] anti-air warfare effectiveness.

  Models of hardkill weapon system performance in the defence of groups against air attack.

  Integrated ship attack battle models.

  Detailed six degrees of freedom engagement models.

- Ship Characteristics

  Models to calculate detailed radar cross section.

  Model to calculate detailed infra-red signatures.

  Models to predict the effects of interference between radar systems.

  Prediction of fire spread.

[47] Specific codes have not been detailed due to their security classification.

[48] A hardkill is where the incoming threat is defeated by being physically destroyed by the defensive measure fired from the ship.

[49] A softkill is where the incoming threat is defeated by some form of electronic counter measure causing it to either miss the target or destruct.

Blast loading tools.

Vulnerability assessment tools.

Shock response and hull girder whipping prediction.

- Sensors

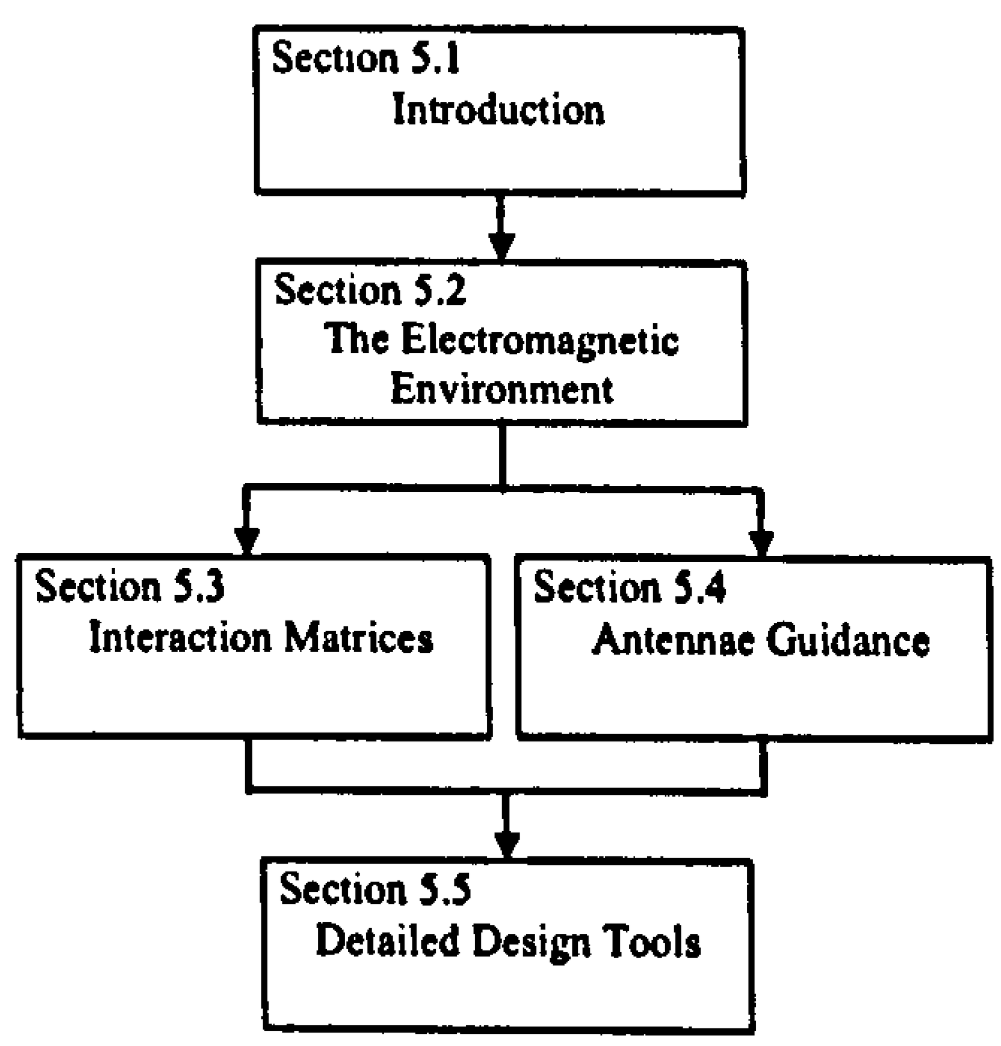
  Modelling of the initial detection and approach phases on an engagement.

  Assessment tools for determining the performance of radars.

  Modelling of phased array radar performance.

The requirement for particular analyses to be performed introduces the need for data conversion and compatibility between different systems. The data within the proposed system is held within the graphical representation and the underlying database records, this data must be capable of export to external programs as required.

5. ELECTROMAGNETIC COMPATIBILITY AND INTERFERENCE



5.1. Introduction

This chapter introduces the problems associated with the electromagnetic compatibility of the different equipment that is required on a warship topside. The ability to predict interference at an early stage will result in less corrective action or operational limitations being placed on the equipment in service. This is a complex issue and the use of the simple techniques described in Chapter 4 are not sufficient to provide guidance. These techniques are still applicable, for example knowledge based systems, but further tools are required to supplement them. The design issues associated with the electromagnetic environment are described and two design guidance approaches are outlined. The first shows techniques available to deal with systems interaction, the second describes methods of providing design guidance for electromagnetic antennae choice and placement. The final section of this chapter introduces some on the advances being made in the more complex modelling tools and describes how these tools will interact with the proposed topside design tool.

Complex techniques requiring extensive topside computer models and intensive processing in order to obtain results do exist [Baron & Cebulski 92], [Bicci et al. 95], [Epsilon 95], [Elbinger & Routier 97], [Parkins et al. 97], [IDS 01], [Rockway et al. 01]. The results from such analyses are useful but the level of design detail required and the time spent modelling is only available during the later stages of the design process and these tools are used to investigate specific problem areas, not the general design evolution [Baron & Cebulski 92].

5.2. The Electromagnetic Environment

Electromagnetic interference (EMI) is a major contributor to degradation in fleet performance and is experienced by all major navies. The extent of the problem has been summarised by Grich and Bruninga with reference to the USN fleet in 1986 and is reproduced here as Figure 5.1 [Grich & Bruninga 87]. Although slightly dated, this comprehensive summary gives a good indication of the extent of the problem circa 1986. The increase in weapon and sensor complexity since 1986 can only result in an increase in the number of possible interference problems.

Image removed due to third party copyright

Figure 5.1 : EMC Problem Population by Ship Type [Grich & Bruninga 87]

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Table 5.1 : Major Losses Due to EMI or EMI 'Fixes', derived from [Grich & Bruninga 87]

The results of problems caused by EMI can be catastrophic, including loss of the ship and crew. Table 5.1, compiled from information contained in [Grich & Bruninga 87] details some of the major losses in both war and peace time, attributes the cause and gives an indication of the cost. It can be seen that the EMI problem is significant and has a major impact on ship operation in both peace and wartime.

The surface warship's topside electromagnetic environment is becoming more complex. The number of antennae have increased[50], the current US DDG51 (guided missile destroyer) has 108 different antennae, each with its own specific requirement [Litton 00], and the radiation characteristics are more varied. The more common radio forms such as continuous wave, frequency modulation and amplitude modulation are maintained but a wider range of frequencies and output power are now transmitted over a single antenna [Gallagher 89].The addition of a super high frequency capability will further exacerbate the problem [Litton 00]. Radars have advanced from the days of measuring characteristics in terms of frequency, pulse width and repetition rate. Traditionally, radar beams have been formed and focussed by a dish antenna that is rotated to provide a surveillance beam or trained to track a target. These are now supplemented by phased array radars where beams are formed electronically in directions up to 45° from the direction in which the array is facing. The beams can be directed almost instantaneously in any direction to simultaneously scan whilst tracking targets. The earlier heavy arrays required four fixed arrays orthogonal to each other but modern lighter active arrays can be rotated so one or two may be mounted higher on the ship. Automatic computer control of electromagnetic radiators is becoming more prevalent as is increased power, which is being coupled with a reduction in human exposure limits[51]. The future will require electromagnetic equipment designers to be more innovative and replace traditional systems with those of more flexibility. Gallagher states that potential solutions to the situation will require increased attention to both topside design and to the tools

[50] The number of antennae on a typical aircraft carrier has increased from less than 40 in 1950 to over 160 in 1974 [Reuter et al. 79]. Similar increases can be expected for all surface ships [Litton 00]. US Navy DDGs have over 80 antennae and CVNs have nearly 150 [Rockway et al. 01].

[51] In 1982 the American National Standards Institute revised their widely accepted standard C95.1 [ANSI C95.1 82]. It lowered the Personnel Exposure Limit (PEL) from 10mw/cm^2 to 1mw/cm^2 over the frequency band from 30 to 300Mhz [Gallagher 89].

provided by the operators [Gallagher 89]. The development of a discipline in electromagnetic engineering comparable in status with that of the naval architect and marine engineer has been proposed. [Grich & Bruninga 87]. This reference concluded that an engineering system is needed bringing together all the requisite scientific, technical and engineering disciplines required to design and predict the electromagnetic system environment and resultant mission performance implications (in quantitative terms) resulting from the active and passive elements that are collocated on a specified surface ship.

It is acknowledged that the electromagnetic environment of the topside of a ship provides a constraint to the design and this must be recognised and considered early in the design [Orem 87], [Valvonis et al. 95] allowing the warship designer to shape the environment such that the electromagnetic field strengths do not exceed design criteria at critical topside locations. The integration of topside electromagnetic environment and electromagnetic subsystems performance into the mainstream of surface ship engineering was presented in a paper entitled "An Electromagnetic Environment Systems Engineering Process" [Judson et al. 87]. The details of the process for the generic electromagnetic engineering procedure are reproduced as Figure 5.2.

The extensive use of flow diagrams within the reference demonstrate that the field of electromagnetic engineering is large and complex, requiring sophisticated tools and extensive analysis throughout the ship design process. Ship design teams have access to computer codes and algorithms requiring detailed levels of definition that make use of the differing prediction techniques that provide some sort of measure of expected performance of particular arrangements [Li et al. 88]. Use of these codes facilitates a process similar to that shown in Figure 5.2 but this process is not applicable to the early concept exploration phases of design. The use of a design procedure such as this at an early stage of design is currently prevented due to lack of initial ship design definition.

Figure 5.2 : Generic EM Engineering Procedures [Judson et al. 87]

5.3. Interaction Matrices

It is possible to make initial estimates and prediction of EMI problem areas at an early stage of design. The two areas that can be investigated are that of the operating frequencies and also the use of prior knowledge and experience into EMI problems. Two tools exist for the use of this knowledge, the first is a frequency spectrum utilisation chart (FSUC) [Juras & Cebulski 92], [NES1049 94]. Figure 5.3[52] shows a sample FSUC chart for illustration purposes with non specific equipment listed.

The communication and navigation transmit and receive frequencies being used by the elements of a ship can be plotted. This chart can then be used to compare the various frequencies, harmonics and intermediate frequencies of the elements. It provides a graphical means of avoiding the selection of elements in a given frequency range that could result in conflict.

[52] Sample FSUC compiled based on the methodology described in [Juras & Cebulski 92] and [NES 1049 94]. Used to illustrate the method, no attempt has been made to use actual equipment data.

Figure 5.3 : Sample Frequency Spectrum Utilisation Chart (FSUC) [Andrews & Bayliss 98]

The operating frequencies of the equipment can be held in the main database as part of the characteristics of the system. As equipment is placed into the design space this information can be transferred to a FSUC that is available for the user to see. Only those equipment items that are placed within the design space would appear on the chart avoiding possible confusion for the designer.

It is not possible to avoid systems having the same operating frequencies, however through the use of the FSUC the designer is able to see which equipment items may have possible conflicts. Where this is the case it may be possible to increase the separation, or include an allowance for shielding, to minimise the problem. The use of the FSUC does not give a measure of the level of interaction and possible system degradation that may occur. What is does highlight is that there may be a possible problem and then steps can be taken to try and minimise the possible problem.

The second tool that is applicable at an early stage is an EMI Source/Victim matrix [Juras & Cebulski 92], [NES1049 94], [QinetiQ 01d]. The EMI Source/Victim matrix lists the transmitters in the left column and the receivers along the top. Where an element is both a transmitter and receiver it is listed in both places.

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Figure 5.4 : Sample EMI Source Victim Matrix [Andrews & Bayliss 98]

Figure 5.4[53] shows a sample matrix with no specific equipment detailed. Each pair of elements is compared and notes made on any previous problems that have been found during their operation and fixes that have been applied[54]. It is not possible to capture this information within the database as it refers to a combination of equipment items rather than an individual item. This matrix has to be held within the overall topside design tool in addition to the main database. It must contain all interaction information and when new equipment is added details must also be added to this matrix. When this matrix is viewed by the user it must only display the equipment items placed within the design space in order to avoid confusion.

The information required for this matrix has to be found from ship records on problems experienced but does then allow for the interrogation of the matrix to provide information on problems and whether there are known solutions that should be incorporated into the design. Using this matrix it is possible to capture

[53] Sample EMI Source/Victim Matrix compiled based on the methodology described in [Juras & Cebulski 92] and [NES 1049 94]. This example has been used to illustrate the method, no attempt has been made to use actual equipment data, problems experienced or fixes applied.
[54] The numbers in the boxes inform on the type of problem experienced and the letters in the boxes refer to the fixes that have been applied to the problem in the past, hence a box with only a number refers to a problem with no known fix.

information about previous designs that would not normally be readily available to the designer.

Typical problems experienced are (compiled from [Juras & Cebulski 92] and [NES1049 94]:-

- Physical proximity
- Adjacent frequency equipment responds to high power or spurious noise
- Transmitter operating as a receiver
- Equipment operating in the same frequency band
- Broadband noise
- Harmonic relationships
- Response to out of band frequencies
- Reflections

Typical appropriate fixes include the following (compiled from [Juras & Cebulski 92] and [NES1049 94] with definitions taken from [Chambers 91]:-

- Bonding

  The electrical interconnection of metallic parts for the safe distribution of electrical charges and currents.
- Grounding

  Connection to earth at one point, or more, for safety or testing.
- Blanking

  Blocking or disabling a circuit for a required interval of time.
- Installation of Radar Absorbent Material (RAM)

  Material which responds to radar waves by attenuating their return echo, thus reducing the radar signal.
- Shielding

  Prevention of interfering currents in a circuit due to external electric fields. Any complete metallic shield earthed at one point is adequate.
- Cam cut-outs

  Physical stops used to prevent equipment pointing in a particular direction.

- Filtering

  Filtering is achieved by selectively attenuating those components of the input signal that are undesired.

Although the two tools, FSUC and Source/Victim Matrix, allow for a basic analysis to be made in order to avoid EMI problems, the geometric constraints also have to be considered.

These two tools form a knowledge based system that can be held within the topside design system. As equipment items are placed on the topside configuration the matrices can be checked for any conflicts. The matrices will need to be compiled from known data, and added to as new equipment items are added to the database.

As a new item of equipment is added to the topside configuration covered by either the FSUC or the source victim matrix the conflict can be flagged up to the designer via a dialogue box. This will show the particular problem that has been highlighted and any known associated fixes. The designer can then make informed decisions as to the equipment placement and the limitations that may be imposed.

When first placing the equipment item into the topside design configuration a warning should be issued if conflicts are identified either in the FSUC or the Source/Victim Matrix. The designer must be allowed to place the equipment where he wishes. A potential conflict must not stop the designer from placing the equipment item, the warning has highlighted a possible problem and this may be addressed later in the design by relocating other equipment. A function within the top level program of the topside design tool will allow for the analysis to be repeated upon demand. It is important that at any point in the design process the user can re-interrogate the design to obtain full details on any warnings or constraints still valid as far as the design is concerned.

5.4. Antennae Guidance

For communications antennae it is important to provide complete coverage of the radio frequency band and this can result in large antennae, the size depends upon wavelength and also polarisation [Gates 87]. The ideal dipole antenna has a most favourable transmission wavelength equal to twice the dipole length [Gates 87]. In reality ships often use a reflected monopole arrangement using the sea surface as a reflector. The most favourable transmission wavelength in this case is four times the length of the antenna [Gates 87]. It can be seen that in order to cover the general frequency band, 2-32MHz several antennae lengths are required, a possible breakdown of this required frequency range into a series of antennae sizes is shown in Table 5.2. Alternatively, base tuners may be used to match the transmitter to a shorter antenna such as a whip or stub. These sacrifice transmitter power (efficiency) to allow the use of a shorter antenna that is easier to site.

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Table 5.2 : Required Antenna Length [Gates 87]

Guidance on the choice of these antennae is captured in the system through the use of a checklist system. In this way the user is prompted to ensure all relevant antennae are included within the design.

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Figure 5.5 : Typical Antennae Configurations [Gates 87]

Accommodating these antennae requires considerable thought at the early design stage to ensure that their placement is both possible and suitably arranged with the required separations. Various configurations are adopted including monopole and folded monopole, roof antenna, whip antenna, bi-conical antenna and stub antenna [Law 83], [Gates 87]. These configurations are shown in Figure 5.5 [Gates 87].

The lengths of these antennae can dictate layout of the superstructure, accommodating a roof antenna requires a separation between mounts of approximately 30m [Gates 87]. Advances are being made to reduce the EMI problem associated with the many antennae required. The Integrated Topside Demonstration System (ITDS) under development by Litton Ingalls Shipbuilding demonstates the integrated implementation of a variety of technologies available to the US Navy for application on DD21 (latest UN navy destroyer design) [Litton 00]. The ITDS structure is formed from composite material and integrated into this supporting structure are a number of embedded phased arrays and conformal antennae, as well as other equipment such as remote illumination systems, exterior lighting, windows, washdown nozzles and watertight doors, Figure 5.6.

Figure 5.6 : Sensors Incorporated into the Integrated Topside Demonstration System [Litton 00]

The aim of this technology is to reduce the EMI problems associated with locating the large number of required antennae on the ship topside. Whilst altering the problem it does not remove the EMI problems. There is still a considerable amount of design work required at the early stages, although some of the sensor integration tasks will already have been performed, to ensure these more advanced sensors and antennae can be located correctly. Similar guidance to that provided for the conventional antennae will be required for the new phased arrays and conformal antennae.

It is important to separate antennae both physically and in frequency. Typical guidelines, taken from NES 1049 [NES1049 94], for conventional antennae, are:-

- Reception antennae should be no closer than 30m to the transmitter antennae if no more than four transmitters are used simultaneously, rising to 60m if more transmitting channels are operated.
- The interaction between reception antennae is far less than between transmission antennae.
- Frequency separation – adjacent antennae should be separated by at least 100kHz up to 4MHz and then by 2.5% above 4MHz.

More detailed requirements can be found in NES 1049 [NES1049 94] and in the detailed requirements for the individual equipment. These guidance documents contain specific limits that are intended to be met. This is not always possible within the constraints of the overall topside design. Details on the effects of degradation, as these limits are compromised, would further aid the designer.

The various approaches outlined in Chapter 4 can be used to capture this information within the system. The size of a particular antenna can be held within the graphical description along with the frequency range that it covers. A graphical overlay can be used to hold the geometric separations that are required. In order to fully capture the information that is available, a basic knowledge based system would be required to contain details about antennae separation. The guidelines for separation are relatively straightforward but as they do not apply to individual equipment, but relate to the separation between items, the separation guidance must be held in a knowledge base that requires interrogation by the designer when antennae are placed on a given topside configuration. The combination of the graphical system and the database allows for interrogation of separation distances. Warnings to the designer would highlight separation infringements. The designer could either ignore the flagged warning or move the item. The 'interrogate' function can be used to re-evaluate the separation distances as the topside design progresses.

5.5. Detailed Design Tools

The preceding subsections have described simple and useful preliminary design tools for EMC and EMI, however it is necessary to also discuss more complex electromagnetic modelling techniques. The capability to use, when required, the expertise associated with these tools is important. If during the development of the design a problem is highlighted by the more simple techniques employed in the proposed topside design tools, the ability to interface with other more extensive tools is required. By using the skills of experts and the more complex design tools that they employ problem areas could be studied in detail, offline from the proposed topside design tool, and then the results fed back. A number of suitable tools exist within the UK, examples developed for the UK Ministry of Defence, and now run by QinetiQ, include MANEAC, MI-RADSIM, MIST and MEGA [Parkins et al. 96]. These are outlined below:-

MANEAC : A modelling tool used to predict the reflected and transmitted signal from a pattern of conductive elements of various geometries.

MEGA : A finite element modelling tool for the prediction of magnetic fields, signatures and eddy currents.

MI-RADSIM : A modelling tool used to predict the effect of interference between two radar systems caused by antennae coupling and to identify potential topside system incompatibilities.

MIST : A tool developed to predict the electromagnetic environment in the topside of a warship providing input to MI-RADSIM to estimate the extent of degradation [QinetiQ 01c].

The geometry and design information from the topside design tool could be exported to these tools and used for more detailed analysis. Development are being made in increasing the availability of tools of this type. A recent development by Ingegreria Dei Sistemi (IDS) is a tool that integrates in a seamless framework a set of electromagnetic computation modules capable of simulating all parameters needed for the EMC and Radar Signature analysis of ships [Bicci et al. 95], [IDS 01]. As shown in Figure 5.7 the Ship Electromagnetic Prediction program (SEMP) contains modules to allow radar/EW antennae location and performance analysis on metallic and non metallic ship structures, antennae radiation patterns, antennae impedance, inter antennae coupling and electromagnetic interference and prediction of radiation hazard on board (on deck and below).

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Figure 5.7 : Ship Electromagnetic Design Framework [IDS 01]

This is run in an integrated modelling environment which can easily interface to other CAD tools. An example of the output is shown in Figure 5.8. Here an interference/EMI assessment for radar/EW has been carried out based on inter-antennae coupling computation.

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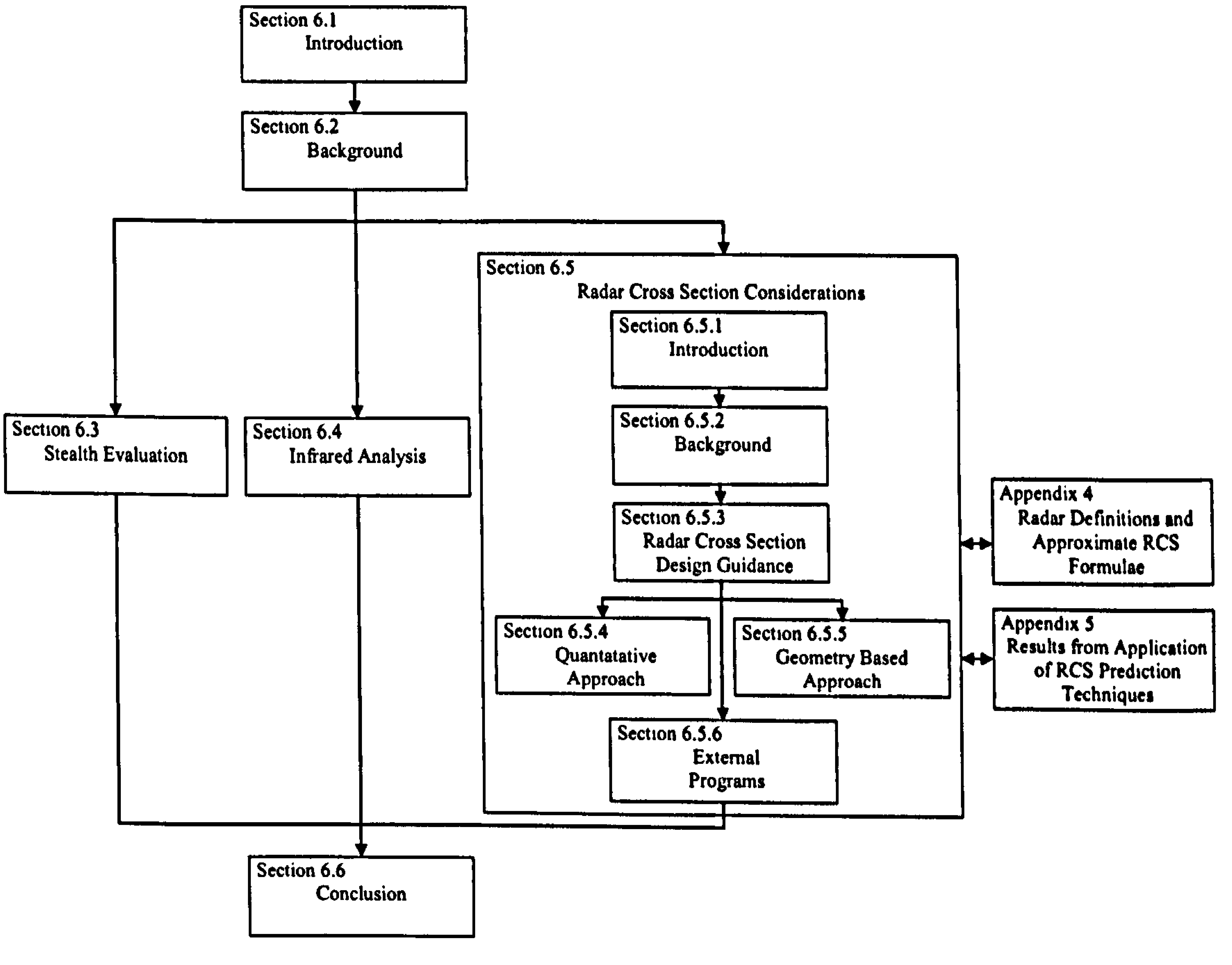
Figure 5.8 : Example EMI Interference Assessment [IDS 01]

This example illustrates the complexity of the calculation and the results but shows that in expert hands complex results can be obtained and the information fed back to the designer for incorporation into the topside configuration within the proposed topside design tool. The simpler tools discussed earlier are more applicable to incorporation into a tool to be used by a single designer who is not a specialist in the EMC/EMI area. It is not the aim of this research to incorporate all available prediction capabilities into a single suite of tools. The aim is to detail the type of tool applicable to the early stages of design and for use by a single designer. These tools, by necessity, have to be simpler than is currently available to the expert. This will allow the non expert to gain useful guidance without having to become an expert in every field. Where possible problems are identified use of specialist tools, such as the Ship Electromagnetic Prediction program discussed above, by experts may be required. As a result there will be a requirement for the proposed topside tool to interface with tools such as SEMP to allow detailed analysis to be performed using information already held in the topside design system.

6. STEALTH AND SIGNATURE CONTROL



6.1. Introduction

This chapter outlines the ship design aspects relevant to stealth and signature control. The topside arrangement of a ship can play a major role in defining the overall signature level of the ship [Turner 97a]. As a result it is important that stealth aspects are considered throughout the ship design. A background section (Section 6.2) presents the topics covered. This is followed by subsections covering three major areas. The first of these considers the evaluation of stealth as an overall concept (Section 6.3). Possible methods are highlighted and discussed and recommendations are made. Secondly the concept of infrared (IR) is introduced and possible methods of analysis are outlined and discussed (Section 6.4). The third topic is a major investigation into Radar Cross Section (RCS) determination techniques given the availability of tools which might be implementable in the proposed system (Section 6.5). A final section draws conclusions from the investigation of these three areas.

6.2. Background

An important aspect of modern warship design is the signature level achieved [Turner 97a], [Friedman & Lok 98], [Peddell & Turner 02]. The aim of the signature reduction is to reduce the susceptibility of the ship and as a result increase the overall ship survivability [Ball & Calvano 94]. The evaluation of signatures, be they acoustic, magnetic, visual, infrared or radar are all collected together, for the purposes of this research, under the single term stealth. A full stealth solution would be a design focused entirely on stealth at the expense of all other aspects. Ships such as the Sea Shadow [Chatterton & Paquette 94], [Linder 94] and SMYGE 2000 [Bergman et el. 95] do not provide valid solutions to a multi-purpose ship design but enable exploration of advanced ship technologies. The use of stealth technology in recent general ship studies has been heavily publicised[55] and relies on the technologies first used in the aeronautical fields [Stinton & Lewthwaite 92]. A recent use of stealth technology as a major part of a ship design has been seen in the SEA

[55] The Euronaval 96 exhibition [Harboe-Hansen 97] included presentation of many stealth orientated designs including Vosper Thornycroft's Sea Wraith [Vosper 96], [Vosper 97], the BAeSEMA designed Cougar Corvette [Friedman 97] and Ingalls 85m corvette design based on the Israeli Sa'ar 5 [Friedman & Lok 98].

WRAITH concept presented by Vosper Thornycroft [Vosper 96], [Friedman 97], [Vosper 97] and the COUGAR concept from BAeSEMA [Friedman 97]. Both incorporate a variety of stealth features including RCS reduction[56], noise reduction and the control of IR radiation, through novel design solutions such as retractable masts [Gilligan 96].

Any method of evaluating stealth measures must be incorporated into a topside design tool as these measures have a large impact on the superstructure configuration and the general topside arrangement. The application of stealth has become a major element of recent warship design such as the UK Type 23 Frigate [Thomas & Easton 91], the French La Fayette [Friedman 96], [Janes 01], the Israeli Saar 5 [Friedman 96], [Friedman & Lok 98], [Janes 01] and Sweden's recently launched Visby Class [Salomonsson et al. 97], [Janes 01]. The reduction of Radar Cross Section is a critical factor in modern warship design and methods are available to reduce the signature [Nicholas & Stratton 96], but also may have seriously limiting operational implications [Friedman 96]. The question of 'How much stealth?' [Goddard et al. 96] is one that is ultimately down to the combination of the specified requirements and the choices taken by the designer but is limited by the type of ship being designed and operational requirements. The issue for the next RN surface ship designs is not whether to incorporate stealth, it is how much [Goddard et al. 96]. A measure of stealth effectiveness is possible through an operational analysis of specified scenarios resulting in a required level of survivability to ensure the requisite level of mission effectiveness. The operational benefits of having air and surface vehicles with low observability in modern warfare is of increasing importance and its significance was clearly demonstrated in the Gulf War. Thus the benefits of the application of stealth to aircraft is seen in Figure 6.1. This figure, although open to interpretation, shows that there are benefits to be obtained through the application of stealth [Giangreco 93].

[56] Significant effort has been made to reduce the topside clutter as this is a cost effective way to reduce the RCS signature [Turner & Barnes 00].

Figure 6.1 : The Value of Stealth [Giangreco 93]

The development of more stealthy naval vessels will run in parallel with the development of counter stealth technology demanding further reductions in observability to avoid detection. There will therefore be an increasing need to assess and quantify the effectiveness of stealth in operational conditions [Graham 93].

For this topside analysis the signatures of interest are IR (Section 6.4) and RCS (Section 6.5) [Peddell & Turner 02], the noise and magnetic aspects [Hubbard & Pocock 99] are mostly concerned with underwater signatures and are beyond the scope of the topside focus of this thesis. Whilst it is true to say that visual signature cannot be avoided, it can be mitigated. Methods have been developed to minimise the risk of visual detection. The use of dazzle camouflage for ships in the Second World War was considered a useful tactic. Through paint effects, most famously still seen on HMS Belfast (Figure 6.2) [Belfast 01], although visual detection was not avoided, the distance, speed and heading information was harder to obtain.

The latest form of this camouflage can be seen in the design for the Swedish Visby Class corvette (Figure 6.3) [MER 97], designed to operate in the Swedish archipelago. With the advances in weaponry and detection techniques the visual signature does not play a major role for most warship designs.

Image removed due to third party copyright

Figure 6.2 : HMS Belfast – Dazzle Camouflage [Belfast 01]

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Figure 6.3 : Visual Signature Reduction on the Swedish Visby Class Corvette [MER 97]

6.3. Stealth Evaluation

An investigation was carried out into the evaluation of stealth [Slater 98] to see if there is a methodology that would allow the general evaluation of stealth techniques within the proposed methodology. The aim of this work, carried out as an M.Sc. project at UCL under the author's supervision, was to identify if suitable tools exist to enable guidance to be provided on the level of stealth required. The investigation considered whether it was possible to determine the relationship between the level of stealth and a measure of the warship's effectiveness.

It is possible that stealth can reduce the susceptibility of a vessel in a hostile situation by delaying detection, avoiding identification, or preventing targeting. This can be summarised by the kill chain, any break or disruption in this chain results in less probability of being successfully attacked (Figure 6.4) [Goddard et al. 96].

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Figure 6.4 : The Kill Chain [Goddard et al. 96]

This can be achieved in a number of different ways, at various levels of cost. It can thus be difficult for a design team to decide how much to spend and which measures to use. Simplified relationships between the investment in stealth and a measure of warship effectiveness were proposed [Slater 98] with the aim of identifying if it was possible to quantify these relationships. One possible relationship is shown in Figure 6.5, suggesting that there are diminishing returns on investment in stealth.

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Figure 6.5 : Proposed Shape of Stealth/Effectiveness Graph [Slater 98]

At the outset of the project it was felt that this was the most likely relationship, however it is not the only possibility. Different relationships were proposed, including, linear sections, steps in the relationship where either further investment gave no return, or conversely where minimal investment provides a step change in effectiveness (Figure 6.6).

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Figure 6.6 : Alternative Shapes of Stealth/Effectiveness Graph [Slater 98]

If quantification of the function between the investment in stealth and a measure of effectiveness were possible then appropriate tools could be developed to provide guidance to the designer.

The nature of the relationships shown in Figure 6.5 and Figure 6.6 are not likely to be simply evaluated. The relationship depends not only on formulation of the problem but also assessment of the perceived benefits. Cost benefit analysis[57] is a possible method to quantify any relationship if it were to exist. Computerised tools have been developed to carry out this complex cost benefit analysis and one such tool, based on Multi-Attribute Value Theory (MAVT)[58], which has been used in recent warship procurement, Equity [Bond 95] was applied by Slater [Slater 98].

Simple models were developed to investigate the implementation of a MAVT approach [Slater 98]. Five areas of spend were identified, relating to five main signature areas. This is not an exhaustive list but was felt to be sufficient to evaluate the tool.

- Acoustic – Radiated Noise
- Magnetic
- Infrared 8-12μm band

[57] Cost benefit analysis calculates the cost of a project divided by the benefit or value it gives. It is generally calculated as the inverse, i.e. benefit to cost ratio, which provides an indication of the increment of benefit which can be gained per increment in cost [Bond 95].
[58] MAVT is a method used to carry out a cost benefit analysis where the problem has a large number of objectives [Sen 91], [Bond 95], [Slater 98].

- Infrared 3-5μm band
- Radar Cross Section

For each of these signature areas different options were proposed and ranked in increasing order of procurement cost implication (Table 6.1).

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Table 6.1a : Options for Signature Reduction for Ships, derived from [Slater 98]

[59] Example options used to evaluate the implementation of the Equity tool. These do not form an exhaustive list of all options needing consideration for a true analysis, expert input would be required.
[60] Sound adsorbing tiles used to reduce sounds transmission.
[61] Methods of reducing transmitted noise by 'bleeding' air into the water surrounding the ship hull.

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Table 6.1b : Options for Signature Reduction for Ships, derived from [Slater 98]

The benefits against which each option was assessed are detailed below, it must be remembered that some benefits work in the inverse sense. The cost of each signature reduction method is also required and has been entered in terms of development cost and procurement cost[63].

- Signature reduction
- Reliability
- Impact on ship operations
- Operational changes required
- Integrated logistic support/through life cost
- Risk
- In service date

[62] A specific type of device used to reduce the temperature of the exhaust plume.
[63] The benefits and costs for procurement and development are used for evaluation purposes. Expert input would be required to establish true benefits and associated costs in a given ship case.

The structure of the finished model is shown in Figure 6.7 [Slater 98]

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Figure 6.7 : Equity Model Structure [Slater 98]

Scores must be applied to each of the five areas of spend, the most favoured option is given a score of 100, and the least favoured a score of 0. Other options are ranked between these two limits. An example of the scores applied to the Radar Cross Section areas are shown in Table 6.2.

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Table 6.2 : Radar Cross Section Scores for Signature Reduction [Slater 98]

In addition to the scores for each signature, the different signatures have to be weighted against each other, this is carried out for all of the benefits in isolation. Additionally the benefits also have to be weighted against each other. The relative

[64] The score allocation here provides a spread of values allowing the influence of particular factors to be investigated, these do not necessarily reflect real case.

importance of each benefit can be assigned. Results can then be calculated and displayed on a cost-benefit graph.

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Figure 6.8 : Cost Benefit Graph [Slater 98]

The differing combinations of options result in the shaded green area. Point P is then entered, this is a combination of reduction measures chosen by the user. What can be seen from the graph is that this is not an optimal solution, Point C offers approximately the same benefit but for a reduced cost and point B offers an increased benefit for approximately the same cost. These options can then be examined by the designer as they appear to offer a superior cost benefit.

This simple model has been used to highlight the complexity, and the required inputs in order to construct a working cost benefit MAVT model. For cost benefit analysis to work it is necessary to allocate the benefit level resulting from a particular measure having a certain cost. This can be reached through consultation with many experts and their recommendations can often be specific to the individual problem. No simple answer is all encompassing and so although these experts could be consulted on a generic problem, the result would not necessarily be valid for all future applications [Slater 98].

The outcome from this project was that no simple guidance could be given. In order to quantify benefits it is necessary to involve a large number of people and have many design details determined. An understanding of the emerging design is required by all concerned in order to sensibly feed into the cost benefit model. It is therefore concluded that to attempt to include such a tool in a preliminary design tool would not aid the designer, and could, if used incorrectly, hinder the design process by over constraining a solution. It is important that the user is aware of the stealth issues and the possible impact on the emerging design. Although no formal guidance is proposed for the topside design tool, the use of a MAVT approach is not ruled out. Once decisions have been taken, the MAVT approach may allow for a comparison exercise to be carried out against various options but this would require the specialist input relevant to the designs in question. It is the requirement for this specialist input that precludes the inclusion of a MAVT tool in the proposed system. The expert input would be required for the design in question, and it is not possible to populate a MAVT model with generic information and obtain correct results.

6.4. Infrared Analysis

The infrared signature of a ship is the difference between the infrared radiation emitted by it and that of the background against which it is seen. The intensity of the signature depends upon many different factors such as the temperature of the external surfaces of the ship and emissions, the emissivity of these surfaces and the temperature of the background. It is not only hot areas that can cause a problem but also cold areas if seen against a warmer background [Thompson et al. 99].

Image removed due to third party copyright

Figure 6.9 : Infrared Image of a Ship [Thompson et al. 99]

Figure 6.9 shows the infrared (IR) image of a ship. It is possible to discern the position of the engine room on the waterline and the funnel is also highlighted. IR images can be used to find the position of a ship but also to allow classification through knowledge of these hot locations on a given ship.

The IR frequencies of importance are split into the following ranges:-

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Table 6.3 : Infrared Frequency Ranges [NES808 88]

The detection of these frequencies is dominated by atmospheric effects which prevent propagation in some frequencies. This results in two frequency ranges that are detectable, 3 to 5 μm and 8 to 14 μm, although scattering and residual absorption still limit detection to ranges of less than 10 kilometres [Gates 87]. Hot spot radiation is in the NIR/MIR range and is caused by high temperatures such as exhausts. The methods of reducing the hot spot radiation consist mainly of shielding, cooling and air entrainment. Warm body radiation is in the FIR region and is more difficult to counter as is radiates from warm bodies such as the overall ship compared to the surrounding sea. In the other regions atmospheric conditions are such that the IR radiation is absorbed and hence is not a signature problem. Proposals for the use of low solar absorbance paint will reduce the overall topside IR signature but are applied to the ship topside once designed. [Surko & Fraedrich 97].

It is difficult to obtain quantitative IR prediction at the concept stage. Some modelling techniques do exist [Jepps et al. 95], [Parkins et al. 96], [Thompson et al. 99] but these require a significant amount of information, or actual measurements taken from the ship in question. This information is not available to the designer at the concept stages of the design. All the topside designer can do at initial design stages is to ensure that the topic is considered and measures taken to avoid likely IR hotspots. The important consideration for the designer is to allow for mitigation techniques within the topside design. Some possible techniques to reduce the IR signature from the main engine exhaust are shown in Figure 6.10 [Thompson et el. 99]. As can be seen these devices add an additional space requirement as well as increasing weight. It is important to allow for cooling devices, as although detailed design work will not be undertaken at the concept stage, the topside arrangement as a totality may be found to be unacceptable at a later stage if space, weight etc. is not provided or allowed for.

Image removed due to third party copyright

Figure 6.10 : Popular Engine Exhaust IR Supression Devices [Thompson et al. 99]

The proposed topside design tool could accommodate basic IR guidance through the geometrical representation of exhausts and intakes. If the propulsion system is known then relevant exhaust and intake spaces can be chosen from the database or specifically defined. These spaces will have allowances for cooling devices and so the designer should be able to produce a topside that allows for the extra space demand. Even if the design has a new system, the item will need to be defined and as such will require the designer to enter information into the database. This database record will include details for allowances and so will prompt the designer to consider the cooling technology to be used for propulsion exhausts. This will be the case for other equipment that may cause hot spots.

It is not proposed to include any further IR modelling as part of the tool but, through an export capability, the geometry could be used in later stages of design within one of the more complex modelling tools. Suitable tools such as IREX [Parkins et al. 96] used by QinetiQ (formerly DERA) [QinetiQ 01a] and the IR signature modelling software SHIPIR/NTCS [Vaitekunas et al. 96] used by Thompson [Thompson et al. 99] are available. In a similar fashion to that discussed for the electromagnetic modelling (Section 5.5) these tools [Parkins et al. 96] are under constant development and the ability to export geometry for analysis offline by experts will remain important.

6.5. Radar Cross Section Considerations

6.5.1. Introduction

Radar Cross Section (RCS) is an important characteristic of a ship and is controlled by the topside layout. It is therefore of great importance during the concept design stages. By considering RCS early in the design [Boccalatte et al. 97] it is possible to build in stealth without major additional cost. To rectify RSC problems once built requires application of radar absorbent material and paint to mitigate rather than eliminate the problems [NES808 88]. This treatment can be expensive and requires maintenance.

Due to the importance of this signature and the availability of possible methods to allow early analysis, a detailed investigation has been undertaken. It was necessary to investigate the available methods in detail and to implement some of these in order to establish if any are applicable for inclusion in the final tool.

This section introduces the concept of radar cross section analysis by firstly providing some background. This is followed by discussion on methods available to the designer to reduce radar cross section signature. A quantitative approach is outlined, including an approximate method before detailing the relevant electromagnetic theory and prediction methods. This precedes detail on the computerisation of these methods into a basic prediction tool. This method is compared to a simpler geometry based approach and results of the two approaches compared. Further discussion is then provided on the use of more complex tools applicable to offline analysis. These tools would not form part of the proposed topside design tool but would by used by experts to analyse the design offline to investigate likely problem areas.

6.5.2. Background

There is a need for the naval architect to have a prediction process for RCS estimation to analyse the placement of large items of equipment on the ship topside. This should show beneficial or penalising topside layout combinations with respect to the vessel's RCS. The analysis needs to be undertaken rapidly so that many possible evolutions can be investigated. By increasing the speed of a process, detail is lost but this may not adversely affect the process at the concept stage as absolute values are less important than an indication of possible conflicts.

The most important constraint on the ability of the warship designer to incorporate stealth features in the design at the preliminary design stages is sufficient computer power to estimate a ship's RCS at a variety of angles (including roll angles) and to be able to adjust the topside configuration and shape to minimise it [Friedman 96]. High powered computer programs have been proposed [Parlett 86] and developed to assess the RCS of aeroplanes and ships [Bicci et al. 95], [Epsilon 95], [Parkins et al. 96], [CADRCS 00], [Demaco 00], [GRC 01a], [GRC 01b], [IDS 01].The penalty of accuracy is that it takes a long time to input the level of detailed information required to run such a detailed representation. For the QinetiQ code RESPECT total analysis can take over 48 hours to run, at 0.1 degree increments around the azimuth after the model has been generated. [Turner 90]. Codes such as CADRCS, although simpler, still take many hours of processing to undertake an analysis (up to 20 hours for a simple frigate) [CADRCS 00].

This topic is very specialised and requires expert knowledge to fully analyse the problem in a given ship design [West & Jepps 97]. However, it is possible to guide the ship designer, be he an expert or not, to avoid obvious mistakes, in terms of RCS, early in the design. A basic understanding of radar and how it operates (Appendix 4.1) means that the designer can avoid incorporating features that would clearly be detrimental to the overall ship RCS signature.

The matter of data exchange is once again important, as it must be possible to provide the final description from the preliminary design undertaken by the naval architect to the expert analyst for full analysis. Currently, such analysis requires detailed description and is performed by large scale computation and is not amenable to the instant feedback required during the generation of the topside configuration. The development of more user friendly code [CADRCS 00], [GRC 01b] does not negate the need to have a good understanding of the RCS modelling methodology. Thus simpler analysis approaches need to be included in the proposed topside design tool, providing guidance without the need for specialist knowledge or data.

6.5.3. Radar Cross Section Design Guidance

The guidance required by a user of the topside design tool is an indication of features where the RCS signature may be a problem, the design techniques can then be implemented and the design re-assessed to see if improvements have been made. Suitable techniques are detailed below, derived from recommendation made in several references [Knott et al. 85], [Maffet 89], [NES809 92], [Stinton & Lewthwaite 92], [Guerreiro 94], [Way 97].

- Minimise superstructure volume reducing the overall topside area.
- If possible reduce the superstructure to one block. This reduces the number of possible multiple reflections between superstructure blocks. If not possible, minimise separation.
- Avoid curved corners and surfaces. These broaden the flash of an RCS spike due to being seen for a greater extent around the azimuth. Their avoidance will reduce the azimuth angle an RCS spike takes up but will increase its magnitude in a single direction.
- Avoid dihedral and trihedral corners[65] and where unavoidable ensure some of the plates are sloped away from the principal angles to reduce direct returns [Knott 77].
- Use tumblehome or flare[66] where possible on superstructure to avoid reflections and possible multi-path effects.

[65] Where two or three flat plates form corner reflectors by being at 90° to each other.
[66] The use of flare can be seen on the forward face of the superstructure on the Type 23 Frigate [Bryson 84].

- Use a single primary angle for sloping of surfaces to reduce the number of possible flashes to one elevation around the azimuth.
- Be aware of the effect of deck sheer forward of the superstructure block. If the plates are tilted aft by a small angle offset from the vertical a near 90^0 dihedral may be produced.
- Keep the superstructure design as simple as possible. Keep the number of corners as low as is practical. These tend to produce a large radar return over a large azimuth.
- Large superstructure blocks such as masts and plated areas must be given greater consideration as they are a lot more important than the main hull in contributing to RCS.

6.5.4. Quantitative Approach

Techniques are available that allow the analysis of simple shapes and reflector geometry and an understanding of the scattering mechanisms which enable broad estimates to be made [Knott et al. 85], [Maffet 89], [NES809 92].

Figure 6.11 : Physical Optics RCS Estimation Formulae, compiled by [Guerreiro 94]

A summary of techniques and the type of geometry for which results can be calculated is shown in Figure 6.11, reproduced from [Guerreiro 94] which was compiled from the references above.

An example of this type of basic analysis has been carried out into prediction of a simple missile RCS, using MATLAB software [Guerreiro 94][67] and was compared to experimentally measured and calculated RCS results quoted in [Knott et al. 85]. Figure 6.12 shows the results from this analysis. The estimation formulae used worked reasonably well for extreme values but were less accurate for regions where the RCS is less than the maximum. This suggests that such methods may be applicable for prediction of extreme values or comparative modelling but care should be taken in the prediction results for values at positions other than those producing maximum reflection.

Figure 6.12 : Missile RCS Prediction [Guerreiro 94]

Merrill I. Skolnik, of the Naval Research Laboratory, produced a paper in 1974 titled "An Empirical Formula for the Radar Cross Section of Ships at Grazing Incidence" [Skolnik 74]. The measurements were made extensively at the X (9.2GHz), S (2.8GHz) and L (1.3GHz) band [IEEE 02] of a number of naval vessels. Ignoring the main peak at the broadside, an empirical formula for a ship was created relating RCS to radar wave frequency and displacement of the ship. For the 50th percentile it is:-

[67] Guerreiro used a combination of the equations quoted in Figure 6.11 to analyse the RCS of a simplified missile shape made up from a combination of geometric shapes [Guerreiro 94].

$$\sigma = 52 f^{1/2} D^{3/2}$$ *Equation 6.1*

where f = radar frequency (MHz)
D = deep displacement (ktons)

With the advancement in stealth reduction design features in recent years this no longer applies since a poorly designed small ship will have an RCS far in excess of a well designed far larger vessel. Through the application of simple electromagnetic wave formulas guidance may be possible. Further work was undertaken in an attempt to define to what level modelling and prediction of RCS is applicable during the concept phases of design [Way 97]. This work was carried out as an M.Sc. project under the supervision of the author and resulted in a computer program used to analyse a number of examples.

The approximate RCS formulas used for this study were the following, as these encompass the major geometric shapes making up a ship topside:-

1. Flat plates
2. Elliptical and circular cylinders
3. Ellipsoids: prolate, oblate or spherical

Also used was Chu's thin wire approximation to represent the corner effects [Crispin & Maffet 65a]. These were then combined using the random phase method [Crispin & Maffet 65b]. Details of these are given in Appendix 4.

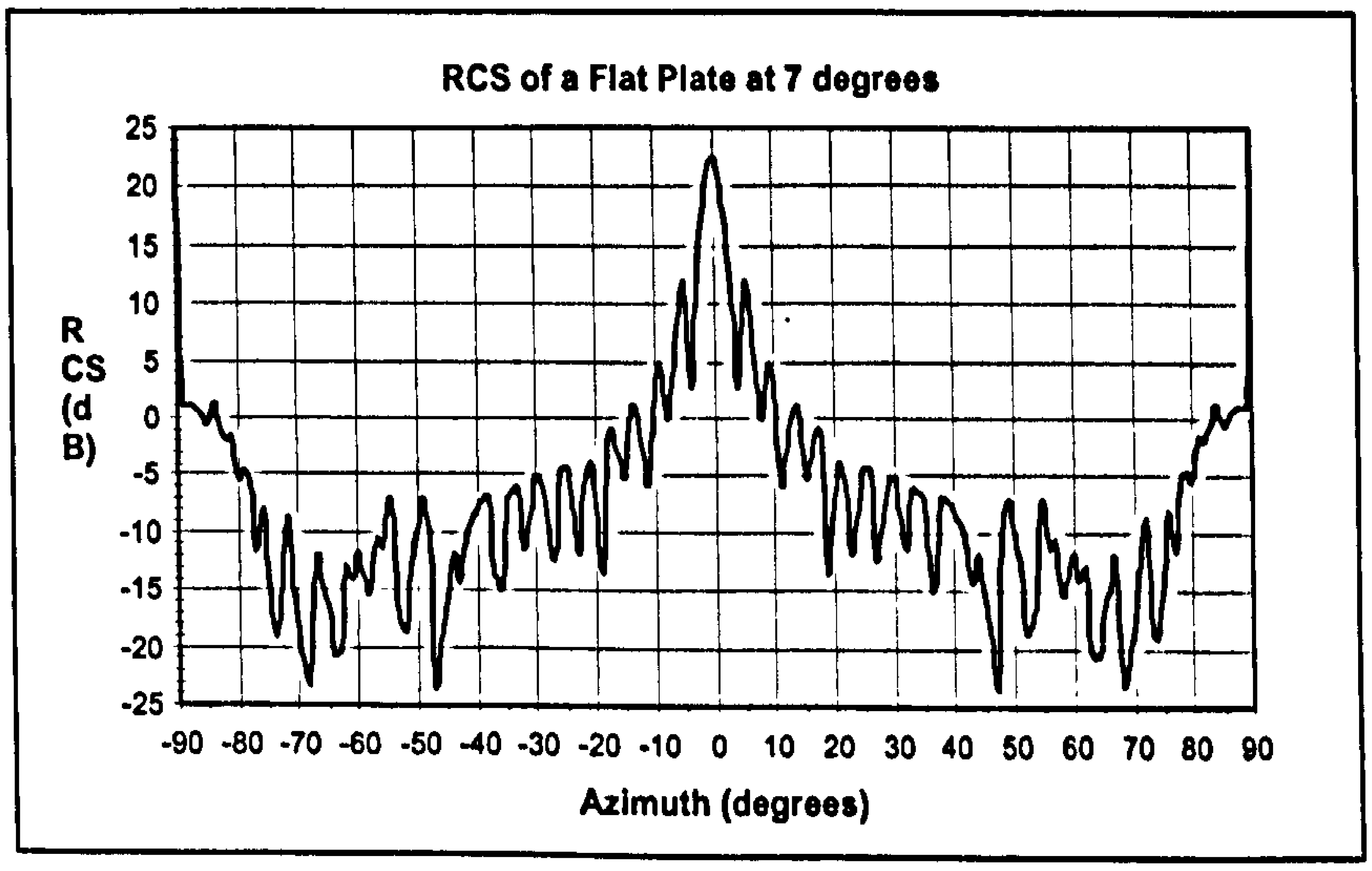

Figure 6.13 : RCS of a Flat Plate at 7°

A number of sample calculations were carried out, as a precursor to the work by Way, using the formula for a flat plate. Figure 6.13 shows the results from one of these calculations, the RCS for a flat plate orientated at 7°. This result is as expected and comparable to results presented by Knott [Knott et al. 85]. This demonstrates that the application of the formulae to simple geometric shapes does result in a measure of the RSC contribution and further investigation was justified.

In order to allow for analysis of various geometries the approximate formulae were coded into a computer program, Single Island Radar Cross Section (SIRCS) [Way 97]. This program was then used to evaluate the predicted RCS of a variety of configurations. A flow chart for the program operation is shown in Figure 6.14.

The approximate RCS formulae lend themselves to producing a simple, but limited, computer program. If superstructure blocks are calculated separately then the program will give an indication of poor orientation and inclination, but is not able to consider multiple bounces of radar energy between different structures. This would require some enhancements to calculate what part of the plates would be in shadow and those which would be illuminated.

In order to provide an indication as to possible problem areas an additional value was calculated, termed the threshold value. This is a value based upon the surface area of the particular shape under analysis. This is a simple calculation that is shown in the following equation [Turner 97b].

$$threshold = \frac{1}{4} \times surfacearea \qquad \textit{Equation 6.2}$$

This value is a basic assumption used to predict the level that would be seen due to general clutter. Whilst appearing very simple it enables the user to see those predicted returns above this level, as it is these returns that will most likely cause RCS spikes. This threshold value is plotted as series of crosses (e.g. + + + + +) on the SIRCS output.

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Figure 6.14 : SIRCS RCS Prediction Program Flow Chart [Way 97]

The SIRCS program has been used to calculate the RCS of various configurations and some sample results can be seen in Figure 6.15. RCS values are presented around the azimuth at an elevation of 0°. Here the larger resulting spike of approximately 60dBsm at an azimuth angle of 30° due to the plate with 0° slope can be clearly seen. For the purposes of the concept tool it is these major features of high RCS that need to be highlighted to the designer.

Image removed due to third party copyright

Figure 6.15 : RCS Prediction Results Using SIRCS [Andrews & Bayliss 98]

The main conclusions of this study are that the approximate formulas are suitable for a single superstructure block case, where multiple reflections are very limited. When the structure becomes more complicated with multiple structural blocks the results from this simple SIRCS program will be incorrect as no account is taken of the multiple returns and shadowing effects, unless the program is enhanced using some form of ray tracing to identify where reflections may occur. However, results have been obtained for a series simple single superstructure models and it is possible to derive from the output graphs whether there are problem areas where the RCS values are high. This output would provide the designer with guidance as to where design changes might need to be implemented. The output can only be used comparatively as the simple application of the formulas does not provide exact RCS values but only provides comparative results.

6.5.5. Geometry Based Approach

Despite research into quantitative mathematical prediction of RCS (Section 6.5.4), carried out as part of this research and aided by the UCL M.Sc. project by Way [Way 97], it was considered that a more novel approach could provide the necessary information to the designer without requiring the complexity of the calculations in the approach just outlined. Other methods may be applicable because the aim of this part of the topside design tool is to aid the designer in avoiding major mistakes early in the ship design process. The aim is not to calculate the RCS of the vessel as that is a highly complex task requiring a high level of definition and large amounts of computer time [Turner 90], [CADRCS 00], [IDS 01].

The major reflectors that contribute to the RCS of a design are geometric in nature. It is possible to identify potential problem features by considering their geometric properties. Although not giving a measure of the likely RCS levels, it would flag up potential problem areas that are known to cause high RCS returns. The 3D CAD model can be interrogated and those surfaces most likely to cause major radar returns can be highlighted. In addition it would be simpler to integrate into the proposed topside design tool. It is recognised that the final RCS of a ship may also be due to many small items of equipment that have to be placed on the ship's topside. However, this approach should enable the designer to avoid features that if retained would subsequently require significant redesign when the ship's topside is analysed in detail much later in the design process.

This subsection introduces the geometric concepts that are proposed for inclusion in the topside design tool. This work is essentially qualitative in nature and has been simulated here. The final RCS identification system would operate as part of the CAD system included in the proposed topside design tool.

After detailed investigation into the best method to use to implement a geometric approach[68] it has been found necessary to separate the approach into three different types of analysis. This enables all of the useful information that can be extracted to be presented in a manner comprehensible to the designer. The three types of proposed analysis[69] are described below:-

Primary Reflectors

The primary reflectors are those that would produce a large return to the search radar. They are essentially those plates that provide a direct return, or near direct return, i.e. a plate at 90° to the incoming signal.

Secondary Reflectors

This is a case where multi-path returns can be highlighted, that is plates producing possible dihedral or trihedral corners.

Design Angle Returns

Here it is possible to choose a principal angle, for example 7°. Once this is chosen plates deviating from this chosen angle can be highlighted. For low RCS flat plates should be sloped to the horizontal or vertical plane, but it is important to try and slope all plates by the same angle, this reduces the possibility of detection by minimising the range of angles over which an RCS spike can be detected.

For all of these cases the basic checks are the same. The topside and above water hull geometry is interrogated and the angles made by the plates to an incoming signal calculated. A graduated colour scheme is then used to highlight the major problem areas. Plates providing a direct reflection are shaded red whilst those at small angles from the normal are highlighted in shades of amber, leading through to green and

[68] This geometric research was carried out by the author making use of a number of CAD tools and manual approaches [Bayliss 98]. Some of the results from the investigations undertaken are detailed in Appendix 5.

[69] The terminology used for the three types of analysis is proposed, by the author, as most suitably explaining the purpose and outcome of each analysis [Bayliss 98].

finally no shade as the angle to the incident wave increases. A suitable graduated scale is proposed ranging from 0° to 15° however this could be tuneable by the designer, by either increasing or decreasing the range, if it were not to meet particular needs. In this way the designer has full control over the analysis that is being performed. The basis for interrogating the geometry would remain the same, altering the graduated scale would alter the shading, in effect increasing and decreasing the allowable deviation from the standard.

For the primary reflectors the principal angle can be set, but by default would be at 0° elevation as this is a major threat axis due to sea skimming missiles. On applying this geometry check, the three dimensional representation would be shaded in colours from red through to green, highlighting any possible problem areas.

For the secondary reflectors the problem is more complex since what is being highlighted are essentially groups of plates that may provide, in combination, returns to the incoming signal. The geometry checks required for this analysis are more complex and the presentation of results is only possible for individual cases. This means that this analysis would be presented in a serious of scrollable options allowing the designer to cycle through all the likely problem cases, with only one being highlighted at a time. The geometry would be interrogated in order to find plates at 90° to each other. This can be achieved by carrying out a range of checks at different principal angles, both in elevation and azimuth. At each angle the geometry could be checked for plates forming intersections of 90°±x° to this axis[70]. This would essentially identify plates that may form dihedrals or trihedrals. When interrogated over a full range of azimuth and elevation angles the tool could present to the designer cases where 90° intersections have occurred as a series of different cases.

For the design angle cases, the checks are fairly simple, the designer would chose the principal angle for the design, i.e. the angle to which most major reflectors are

[70] The designer would input the tolerance required, i.e. the x°. This would allow the investigation to be carried out only identifying 90° dihedral and trihedral cases when x is specified as 0° or with a more relaxed tolerance if the designer wishes to see if any plates are close to forming dihedral/trihedral reflectors.

sloped. The geometry check will then highlight any surfaces deviating from this principal angle. The same graduated colour scale previously outlined can be used, however, this time the red colour is applied to surfaces deviating from the chosen angle. Those surfaces near, or at, the principal angle would be highlighted in green[71].

In order to evaluate whether the geometric approach [Bayliss 98] can provide the required design guidance information it has been simulated for the 19 test shapes that were analysed by the SIRCS program [Way 97]. These test shapes start with a simple box, the geometry is then modified through the inclusion of an angle of slope to the sides of the box. The geometry is then further complicated by the inclusion of a chamfer at different angles which is investigated with different angles of slope. Further complexity is then added by considering a square mast placed on the top of the box with different slope angles and similarly for a circular and oval mast. Finally the effect of different height masts is investigated. The configurations investigated are detailed below.

Model 1 : Simple box, all plates at 0°

Model 2 : Simple box, all plates at 5°

Model 3 : Simple box, all plates at 10°

Model 4 : Box with chamfer at 30° with 0° incline, 3 plates at 7° incline

Model 5 : Box with chamfer at 30° with 7° incline, 3 plates at 7° incline

Model 6 : Box with chamfer at 45° with 0° incline, 3 plates at 7° incline

Model 7 : Box with chamfer at 45° with 7° incline, 3 plates at 7° incline

Model 8 : Box with chamfer at 60° with 0° incline, 3 plates at 7° incline

Model 9 : Box with chamfer at 60° with 7° incline, 3 plates at 7° incline

Model 10 : Base with 7° incline with square mast at 0° incline

Model 11 : Base with 7° incline with square mast at 7° incline

Model 12 : Base with 7° incline with circular mast at 0° incline

Model 13 : Base with 7° incline with circular mast at 5° incline

Model 14 : Base with 7° incline with circular mast at 10° incline

[71] In a similar fashion to that outlined for the primary reflectors the graduated scale would be tuneable to meet the needs of the designer.

Model 15 : Base with 7° incline with oval funnel at 0° incline

Model 16 : Base with 7° incline with oval funnel at 5° incline

Model 17 : Base with 7° incline with oval funnel at 10° incline

Model 18 : Base with 7° incline with short square mast at 7° incline

Model 19 : Base with 7° incline with tall square mast at 7° incline

The SIRCS analysis carried out by Way [Way 97] has been verified and the same geometry analysed, as part of this research, using the geometric approach [Bayliss 98]. The result from the SIRCS analysis is shown graphically [Way 97]. All SIRCS analysis has been carried out using a frequency of 9.5GHz, corresponding to X-band radar [IEEE 02]. This is a commonly used band for radar [Janes 01]. An azimuth angle of 0° corresponds to a broadside view, -90° is a view from the stern, +90° viewed from the bow. This can be compared to the results from the geometric analysis which uses shading of different colours to highlight areas of concern in red, possible problem areas in yellow, with areas of no concern in green.

Due to the simplicity of the geometric technique no program has been used to carry out this analysis, the basis of the technique is to interrogate the shape geometry and identify those surfaces that may cause potential problems. For the simplistic test shapes this has been a manual task [Bayliss 98]. In the proposed topside design tool the geometry to be interrogated will be more complex and it will be automatically interrogated by the tool to avoid the designer having to visually analyse the geometry. The primary reflectors present a direct comparison to the SIRCS analysis. For the additional techniques, secondary reflectors and design angle returns results are not calculated for all models as the simplistic nature of the geometry either does not warrant analysis or does not result in reflections of these types.

An example of the results obtained are shown in Figure 6.16, which is a direct comparison to Figure 6.15. It can be seen that although giving no indication of RCS values, the problem area is clearly highlighted. This is an example of primary reflectors analysis, as this is the only case that the SIRCS program calculates.

[redacted]

Figure 6.16 : Geometry Based RCS Modelling [Bayliss 98]

When comparing model 1 (Figure 6.17) with model 3 (Figure 6.18) it can be seen that both techniques show that model 3 has a reduced RCS when compared to model 1. In the SIRCS output the peak value is reduced from approximately 80dBsm to approximately 30dBsm. The peaks occur at –90°, 0° and +90° and correspond to the three flat plates forming the sides of the box. This problem area is clearly highlighted in red for model 1 in the primary reflections of the geometric analysis. The advantages gained by sloping the sides in model 3 are reflected in the light green shading replacing the red. The designer is immediately aware of the problem area without having to correlate the azimuth angle on the SIRCS output to the geometric model. The geometric technique is also able to output design angle returns, in both cases this results in a green shading explained by the fact that a different design angle is specified in each case. For model 1 the required design angle is 0°, and so the plates all correspond to this angle, this is similar for model 3 where the design angle is 10° resulting in green shading.

A comparison of model 10 (Figure 6.19) and model 11 (Figure 6.20) illustrates not only the primary reflections but also the secondary reflections. From the SIRCS output the peaks again occur at –90°, 0° and +90° but no distinction is made between the contribution from the base and that of the mast. The sloping of the mast reduces the peak RCS level from approximately 70dBsm to 40dBsm. This indicates that model 11 has a reduced RCS when compared to model 10 which is as expected. The primary reflection output clearly shows where the problem contribution to RCS is coming from by shading the mast in red for model 10. The advantage of the slope is shown with the shading altering to yellow for model 11. The secondary reflection output provides more information than is obtained from SIRCS. In model 10 the sides of the mast and top of the base are highlighted in red. This is because they are at 90° to each other forming a dihedral reflector, this 90° angle is removed in model 11.

A comparison of model 18 (Figure 6.21) and model 19 (Figure 6.22) shows that whilst the SIRCS output differs in magnitude, 35dBsm for model 18 as opposed to 37dBsm for model 19, due to the different height of mast, the colours of the geometric shading remain the same. Whilst appearing to be a shortfall in the geometric method, it is still clear to the designer that the masts are of different size as all information is displayed geometrically[72].

The results, comparison and discussion for all 19 models can be seen, in a similar format to that presented here, in Appendix 5.

[72] The designer should be aware that a larger reflecting surface will have a greater RCS.

This investigation has highlighted that there is no additional benefit in the formula based approach above the geometric approach proposed. The numerical output from the SIRCS program contains far more information than is displayed in the graphical output, the additional information is an indication of how the RCS values vary with azimuth. However, due to the simplicity of the approach, the output can only be used in a comparative manner, the absolute values do not necessarily reflect the actual RCS returns. As a result of this it can be seen that the major information gained from the graph is the major spikes. These spikes indicate areas of large RCS return but are also highlighted by the graphical approach. The SIRCS analysis is currently limited to single portions of superstructure, to implement this formula based approach on a multiple superstructure design would require significant enhancement to deal with possible multiple reflections.

The benefit of the graphical approach is that the results are displayed in the same graphical window used for the rest of the design process. The areas of concern are highlighted on this three dimensional model. The SIRCS analysis requires additional input and output and it is then the user's responsibility to link the spikes on the output graph to the geometric elements creating the spikes.

In addition to the direct RCS returns the graphical based approach allows for presentation of additional information in a similar fashion, Secondary Return and Design Angle Returns.

6.5.6. External Programs

The aspect of RCS is one where resorting to programs external to the proposed topside design tool will allow more information to be provided to the designer. The aim of the proposed system is that all feedback will be immediate and at all times reflect the geometry of the design at that point in time. This means that complex RCS modelling tools are not applicable. However, through the export capabilities of CAD systems the model can be exported to an external system for offline analysis. This will allow more complex analysis to be carried out, if required, once the model geometry definition has been suitably detailed. There may be a requirement to write export/import filters to ensure that the correct data is exchanged but the use of standard CAD transfer formats such as IGES [IGES 96] and STEP [ISO10303 01] should mean that this is not an onerous task as the majority of the CAD information should export/import correctly.

RCS modelling software has always been highly complex, and due to the computationally intensive nature of the analysis has required high power computing facilities [Turner 90]. Even on these high end computer platforms a full analysis takes many hours, or even days [Turner 90], [Turner 97b]. In addition to the time factor, the field is highly specialised and the current tools require an expert user in order to produce accurate results. Two such systems in use in the UK are the MOD developed Respect [Turner 90], [Turner 97b], [Turner & Barnes 00] and Epsilon, from Roke Manner Research [Epsilon 95]. In the USA there is a prediction code Xpatch available from Demaco Inc. [Demaco 00].

As computing power has increased over the past five years there is now the opportunity to implement computationally intensive programs on a standard PC or readily available workstation. Examples are Spectre [QinetiQ 01b] and CADRCS [CADRCS 00]. CADRCS is being further developed to integrate with the Paramarine ship design software [GRC 01a], [GRC 01b], [Paramarine 02]. This program has been developed to accept a geometry file and with additional, radar specific, input allow the RCS of the model to be determined and displayed graphically (Figure 6.23).

Figure 6.23 : Example of CADRCS Calculation [CADRCS 00]

This process is still time intensive, taking up to 20 hours to analyse a simple frigate design [CADRCS 00], but is available on a standard PC, the platform any proposed topside design system is likely to run on.

The Ship Electromagnetic Design Framework (SEMP) outlined in Section 5.5 with reference to the EMI capabilities contained within the program modules also has the capability to carry out Radar Cross Section analysis [Bicci et al. 95], [IDS 01]. The example shown in Figure 6.24[73] illustrates the identification of hotspots[74] on the ship structure directly on the models used in the CAD system. This again demonstrates the availability of complex RCS modelling capability if the detailed radar specific input is known.

Figure 6.24 : Identification of RCS Hotspots by SEMP [IDS 01]

Due to the complex nature of RCS modelling it is proposed that a facility within the proposed topside design tool exist to export the topside geometry to tools such as those outlined. The inclusion of a program such as CADRCS [CADRCS 00] or SEMP [Bicci et al. 95], [IDS 01], running on the same computer platform as the topside design tool, will allow the ship designer to run offline analysis of the model

[73] The SEMP model considers three contributors to the overall RCS. Direct reflections and multiple reflections are included along with wedge diffractions. These wedge diffractions are contributions to the return radar signal due to the presence of the edges of the structure [IDS 01].

[74] The term hotspot refers to an area of the geometry providing a large RCS return.

and obtain RCS results. Where more detailed modelling is required the use of the more specialised tools will have to be carried out by an RCS modelling expert. This will require the system to have the capability to export the geometry from the topside design tool to the specialist RCS package.

6.6. Conclusion

This chapter on stealth and signature control has discussed a range of concepts that may provide useful information to the topside designer. However, as has been argued in the individual sections, not all have been found to lend themselves to inclusion in the proposed topside design tool.

The area of stealth evaluation encompasses many aspects of ship design. From the investigation, summarised in this chapter, it is clear that there is a resultant bias towards the RCS aspects when considering the topside design environment. Unlike IR, the RCS of a target is only influenced by the topside design. The IR aspects are far more complicated and result from decisions made about the internal layout, engine choice, trunking routes and exhausts. Of these the topside designer is able to influence the exhaust, but the remainder form part of the total ship design. The topside designer cannot become divorced from the total ship design but it can be seen that there is far more importance placed on the topside environment when considering RCS. This bias has been reflected in the investigations and proposed solutions, more effort has been focused on the RCS issue with additional modelling techniques proposed. The findings from the three main areas of investigation are summarised below.

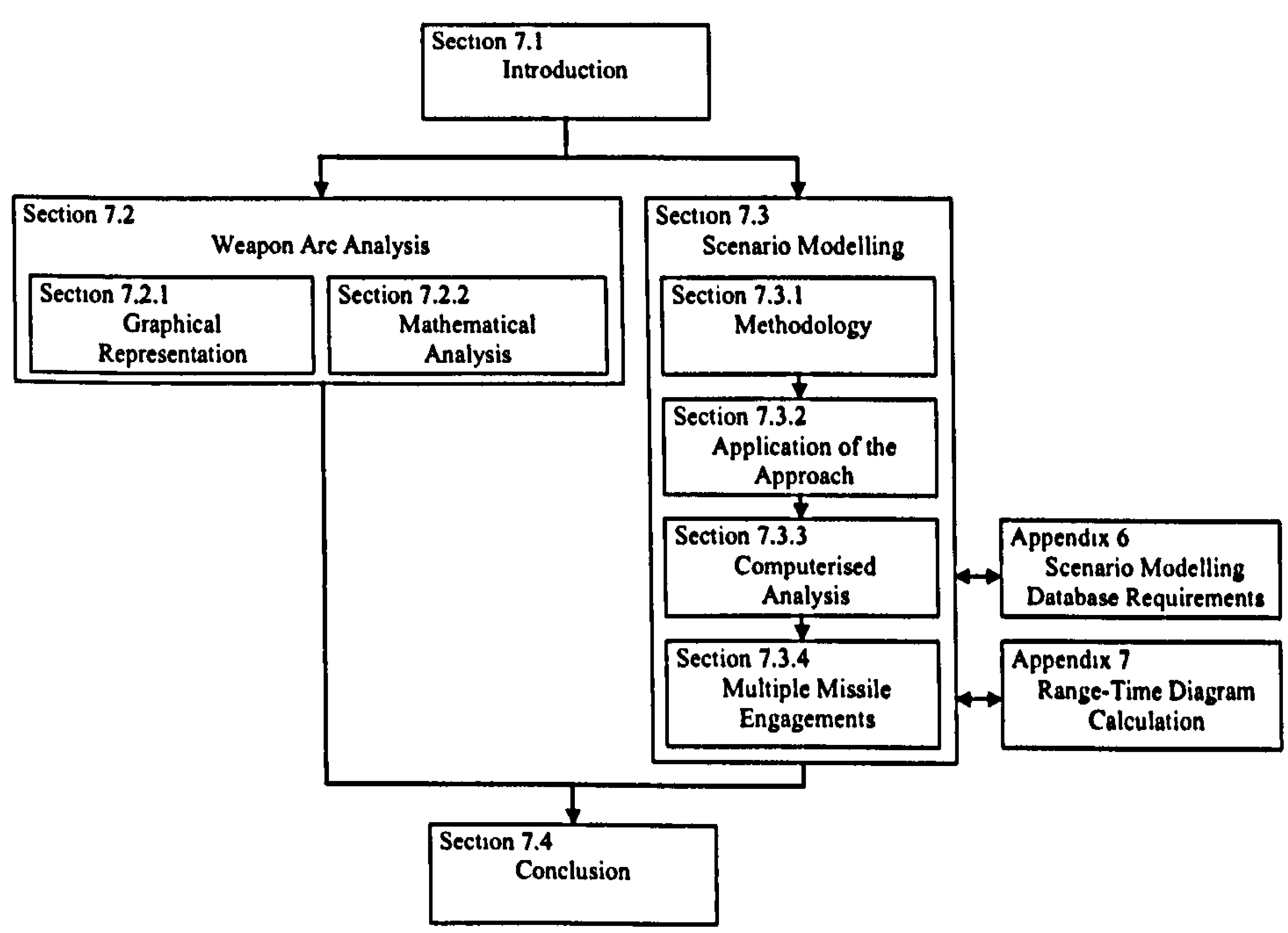
The stealth evaluation investigation (Section 6.3) has shown how complex any analysis would be to provide useful output. Although it is possible to obtain useful results through the use of cost benefit analysis [Slater 98], the level of detail, and the knowledge required in order to develop the model would not be available to the designer at the concept stages of any currently conceivable ship design. Indeed it is concluded that trying to implement any of the methods outlined in the stealth evaluation section (cost benefit, MAVT) could result in overconstraining the designer for reasons which may not be immediately apparent, and may not be the most important for the particular design.

As far as IR analysis is concerned (Section 6.4), for the proposed system it would appear to be more appropriate to include a prediction capability. The use of geometrical representations, including the space taken up by measures taken to combat IR, would ensure these items are considered. It is not possible at this broad preliminary level to predict actual values, to do so would be excessive, and all that is required is that the equipment items are defined such that measures to counteract the IR signature are included in the model.

The detailed RCS investigations (Section 6.5) have shown that there are many methods that could be used to predict the RCS of the vessel under design. The proposed geometry based approach can flag up the same problem areas as the application of RCS formulae. The results can also be more easily interpreted, as they are displayed on the geometry screen, without requiring separate graphs and the need to correlate these graphs with particular geometrical features. The geometry based approach can also be used to highlight possible multi-path returns without major additional difficulty.

The use of external programs for IR evaluation and RCS prediction has been discussed and some of the available programs detailed. This highlights the requirement for the proposed topside design tool to be able to exchange data with other computer codes.

7. WEAPON COVERAGE AND SCENARIO MODELLING



7.1. Introduction

A major area requiring consideration during the development of any warship topside is the placement of both the offensive and defensive weapons and decoys. By their nature these items can be considered to be the most important items topside as they normally are the primary features required to meet the military capability.

This chapter presents the methods available to the warship designer to help select and place these systems. There are two distinct areas, those related to weapon arc analysis and a scenario modelling method. Both are seen as being additional to the three dimensional graphical presentation of the emerging topside design provided by the topside design tool.

For the weapon arc analysis (Section 7.2) two methods are discussed, the purely graphical representation of Blockage Assessment Models (BAM) (Section 7.2.1) and a mathematical method which allows a quantitative comparative analysis to be made between differing layouts (Section 7.2.2). Each is demonstrated and developments shown which improve their suitability for incorporation in the proposed topside design tool. The second major section introduces the concept of scenario modelling and outlines a basic approach that can be applied (Section 7.3). Examples of this are shown and the need for computerised analysis demonstrated. A possible method for computerised implementation is described [Skarda 98] and shortcomings discussed before a graphical approach is presented.

Conclusions are drawn and recommendations made with regard to the various tools utility in the proposed topside design tool.

7.2. Weapon Arc Analysis

7.2.1. Graphical Representation

The topside arrangement on a warship is particularly complex, and even in a 3D environment can be difficult to visualise, so aids to placing topside features are useful. A simple tool is the Blockage Assessment Model (BAM)[75 76]. This is easily understood and provides direct information on weapon and sensor coverage. Figure 7.1 shows an example for a given weapon located on a frigate forecastle[77].

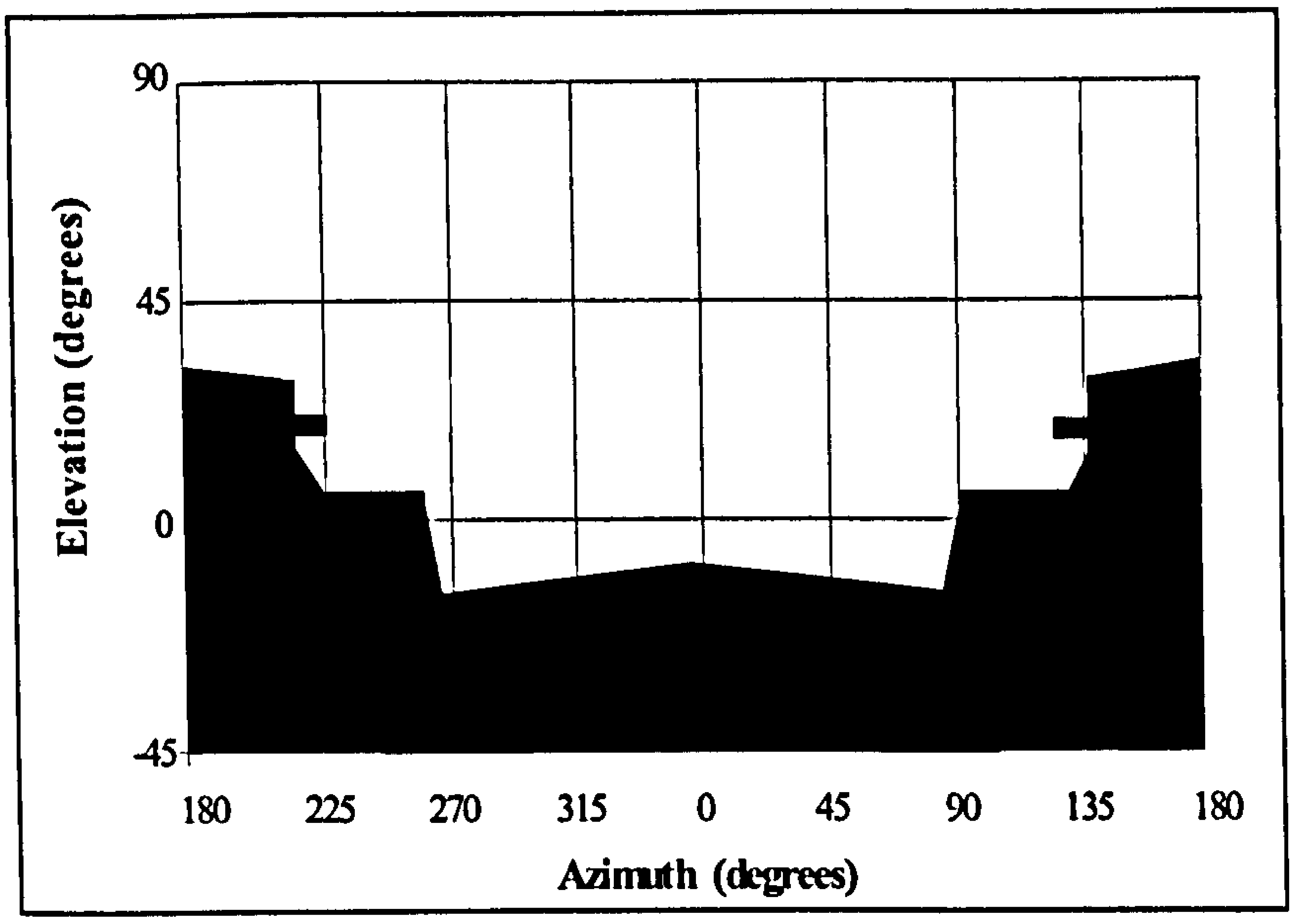


Figure 7.1 : Sample Blockage Assessment Model

A plot is made of bearing (azimuth) against elevation for each topside location being considered as a possible equipment position. The unrestricted field of view is shown clear whilst any restriction by ship structure or other equipment is shaded. In the

[75] The Blockage Assessment Model (BAM) is a common tool used to illustrate the available field of view a particular system has from a particular location on the ship. Details can be seen in [MIT 96], [UCL 96] with discussion about usage in [Law et al. 87], [Juras & Cebulski 92], [Andrews & Bayliss 98].

[76] An early computer implementation of the BAM can be seen in the UK MOD ship design computer program GODDESS [Pattison et al. 82], [GODDESS 94]. The WEPSEN module, within the GODDESS program, carries out a crude field of view calculation and displays this in wireframe format [GODDESS 94], [Bayliss 97]. Improvement in computer graphics capability should allow modern CAD systems to calculate and display the BAM model more readily.

[77] The sample BAM shown here has been developed for illustration purposes within this thesis and relates to position forward of the superstructure. The bow can be seen at an azimuth of 0° with superstructure blockage starting at approximately 90°. The main superstructure bridge and bridge wings can also be seen.

example shown, for weapon launcher location, the position is on the foredeck, in front of the main superstructure, the effect of the bow shape is shown with the block of superstructure blocking the field of view and the bridge wings effect clearly seen. This gives an immediate indication of the restrictions in coverage for the weapon launcher or sensor in any given location on the upper deck. The total blockage picture can only be seen when this restricted field of view is combined with the individual piece of equipment item's own restrictions on operation. Within the proposed topside design tool this BAM model is extended to automatically include the system limitations, described below.

For items of equipment the blockage assessment diagram is made up from each equipment's blockage model and the resulting blockage model from its placement within the topside environment. Most weapons or sensors have built in blockage[78], for example a Mk8 4.5″ gun has elevations from -10° to 55° over an azimuth of 340° [Hooton 98]. This blockage has to be combined with the blockage in the current position to produce a composite picture. A real time display of this blockage model will help the designer place the equipment in the design space maximising the clear arcs. An example of the combination of the Mk8 4.5″ gun with the blockage for the demonstration BAM model shown in Figure 7.1 is shown in Figure 7.2.

Once the complete weapon system has been placed it is proposed that a composite picture be produced for the whole system[79] combining several trackers and launchers into one blockage diagram. This will be important for systems such as Vertical Launch Seawolf where the ship may have several trackers [Hooton 98]. By combining the results of all the tracker positions a composite plot can be produced allowing immediate indication of any blind spots. This composite plot can contain additional information by using a colour code system to show which areas are covered by one tracker, which have combined coverage by two trackers, or even

[78] For trainable systems there will be a mechanical stop limiting movement in both azimuth and elevation to that practical for design purposes. Fixed systems may still have blockage due to their housings.

[79] A weapon system is often made up from many topside components such as the main ship radar, a number of tracker radars and weapon launchers/silos. There may be a requirement for some or all of these elements to be able to see the target, therefore a single equipment BAM may not suffice.

three or four. The simple conclusion that can be drawn is that trackers/directors should be placed so that in combination they provide the most coverage.

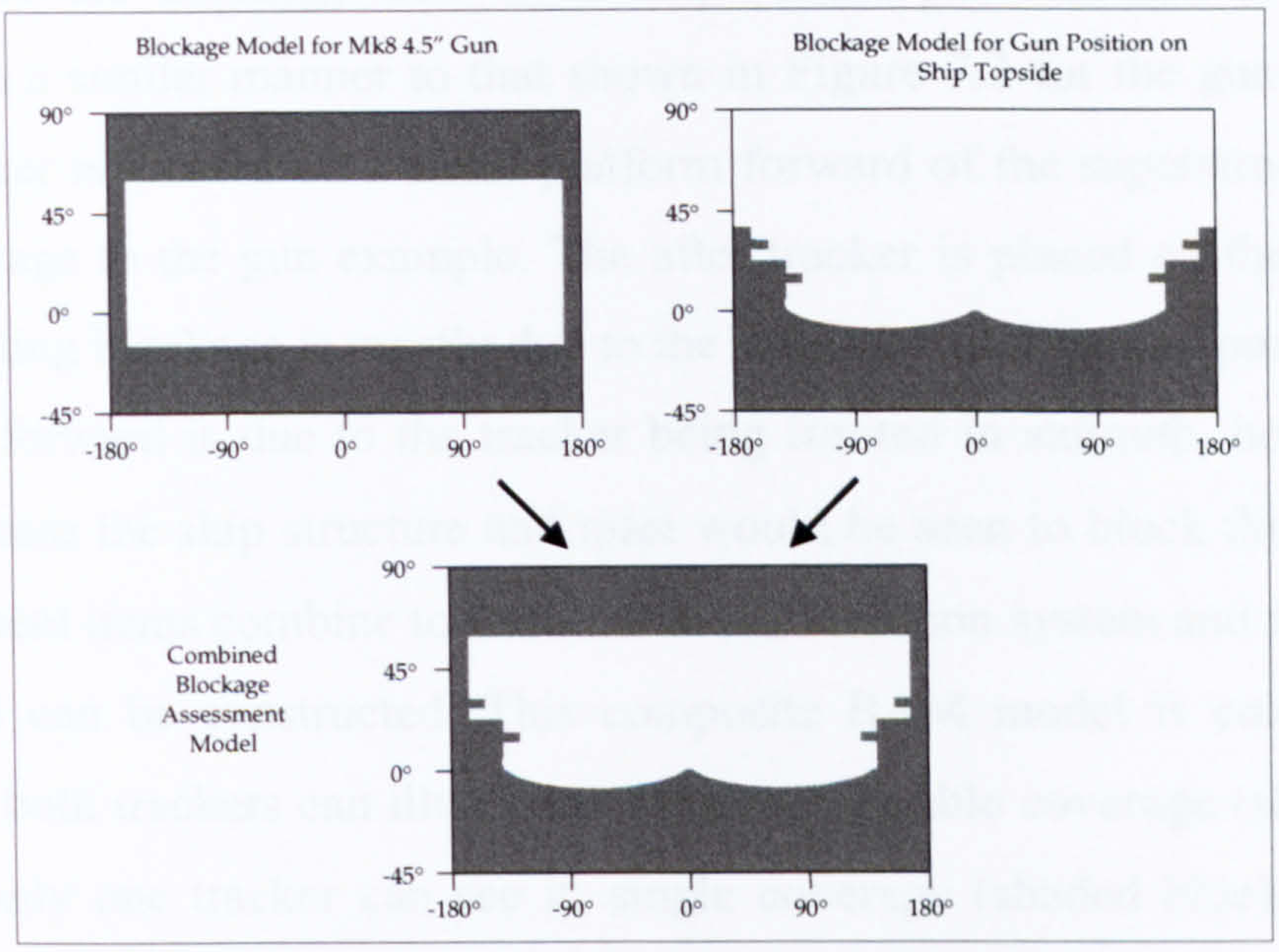


Figure 7.2 : Combined Blockage Assessment Model (for Mk8 4.5" Gun)

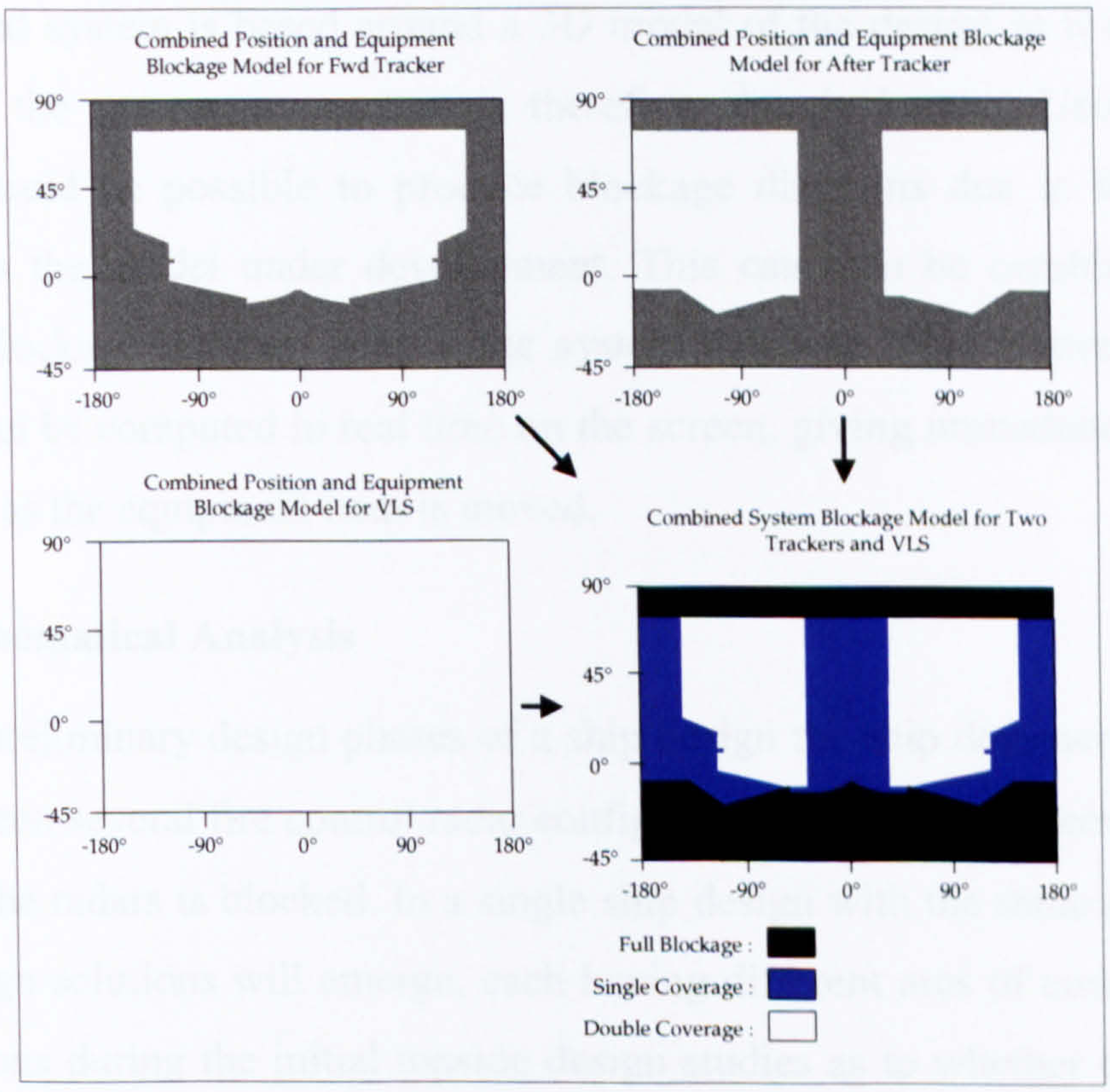


Figure 7.3 : System BAM Model for Two Trackers and a VLS

The example shown in Figure 7.3 shows the combination of two trackers and a vertical launch silo. The silo is assumed to have full 360° coverage and be unlimited in elevation, as a result the BAM for this part of the overall system is unlimited. The individual BAM models for the two trackers are shown. These are themselves composites of the blockage due to the equipment position and the equipment limitations in a similar manner to that shown in Figure 7.2 for the gun system. The forward tracker is located on a small platform forward of the superstructure, having similar blockage to the gun example. The after tracker is placed on the hangar roof and the resulting blockage is mostly due to the limitations of the equipment. The area of blockage forward is due to the tracker being limited in azimuth, however if this was not the case the ship structure and mast would be seen to block this area. These three equipment items combine to form the overall weapon system and the composite BAM model can be constructed. This composite BAM model is colour coded to show where both trackers can illuminate the target, double coverage (shaded white), and where only one tracker can see it, single coverage (shaded blue). The area of total blockage is shaded black.

The envisaged system is based around a 3D model of the design as it evolves. The geometry of the system in question is therefore already known. Using the CAD system it should be possible to produce blockage diagrams due to the geometry directly from the model under development. This can then be combined with the equipment blockage diagram held in the system database. This is straight forward and hence can be computed in real time on the screen, giving immediate feedback to the designer as the equipment item is moved.

7.2.2. Mathematical Analysis

During the preliminary design phases of a ship design the ship designer may have to decide between several fire control radar configurations in which the coverage of one or more of the radars is blocked. In a single ship design with the same set of sensors several design solutions will emerge, each having different arcs of coverage. It may not be obvious during the initial topside design studies as to whether one particular arrangement of sensors is better than another, the different proposed options may appear to provide similar coverage. In addition to the BAM proposed a further method is required to assess which of the solutions is preferable.

The problem appears to lend itself to a simple calculation of the average number of systems available around the azimuth which would then provide additional information to the BAM diagrams allowing differences between the proposed topside arrangements to be analysed quantitatively. This proposed approach is outlined below and the limitations demonstrated.

Figure 7.4 shows two possible configurations for a system consisting of two radars. In both configurations Radar A and Radar B have a blind arc of 45°, the first configuration has the blind arcs separated and in the second configuration they are overlapping and the ship is consequently blind over this small sector[80].

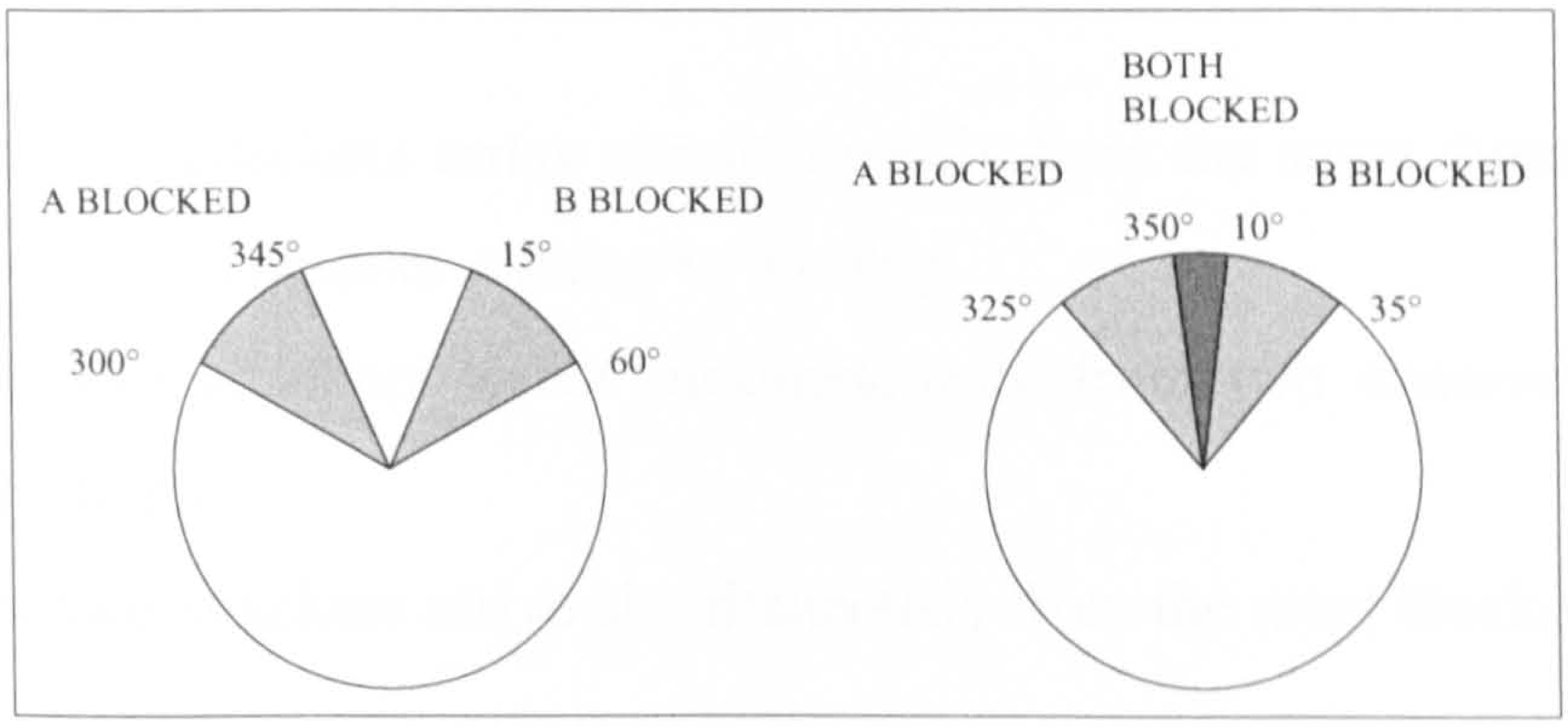


Figure 7.4 : Radar Blockage Configurations

If we carry out an analysis based on the average number of detectors available with these two detectors, then:-

$$Average = \left(2 \times \frac{Full^\circ}{360^\circ}\right) + \left(1 \times \frac{Blocked^\circ}{360^\circ}\right) \qquad \text{Equation 7.1}$$

Where : *Average* : average number of detectors available

Full : angular extent of full coverage

Blocked : angular extent of single blocked coverage

Therefore for the first case

$$Average = \left(2 \times \frac{270}{360}\right) + \left(1 \times \frac{90}{360}\right) = 1.75 \qquad \text{Equation 7.2}$$

---

80 For this demonstration case the BAM would have highlighted the problem of zero coverage. This example is used to demonstrate the failings of the simple mathematical approach.

and the second case

$$Average = \left(2 \times \frac{290}{360}\right) + \left(1 \times \frac{50}{360}\right) = 1.75 \qquad \textit{Equation 7.3}$$

This simple analysis of these configurations considering the angular extent of blockage has showed that the second configuration is not penalised for double blockage, clearly a worse case[81]. Thus an approach based on average number of illuminators available is unconvincing, therefore a more involved assessment method is proposed by Mangulis [Mangulis 79]. This considers the number of incoming enemy attackers that cannot be illuminated and uses this to enhance the analysis. The results in Table 7.1 are for three assumed scenarios:-

1. The two attackers arrive simultaneously from the same direction, but that direction is random relative to the ship.
2. The two attackers arrive simultaneously from two uncorrelated random directions
3. The two attackers arrive simultaneously from the most blocked direction.

Enemy Strategy	Expected number of attackers which cannot be illuminated	
	Configuration 1	Configuration 2
Strategy 1	0.250	0.250
Strategy 2	0.031	0.121
Strategy 3	1.000	2.000

Table 7.1 : Weapon Configuration Decision Matrix

It is clear that in contrast to the earlier simplistic analysis, this approach highlights the difference between the two configurations investigated. Configuration 1 can been seen to be more preferable to Configuration 2.

[81] This result can be shown to be true in general for any configuration. In addition if we consider the case where each radar is blocked over a reduced arc of 35° but both are blocked over the same arc the result is calculated as 1.806, appearing favourable to the two cases presented which is clearly incorrect [Mangulis 79].

It is proposed that this mathematical approach be available to the designer as part of the topside design tool. A series of enemy attack scenarios could be chosen and analysed against a particular system. The data detailing the extent of single and double coverage would be derived automatically from the BAM plots. This would allow the naval architect to assess the benefits of different topside configurations.

7.3. Scenario Modelling

7.3.1. Methodology

During the development of a topside layout it is possible to evaluate different solutions against a scenario devised by the designer [MIT 96] to inform the choice and location of weapon systems. It is possible to evaluate the design and obtain a comparative measure of how each solution would perform against a proposed threat scenario. Using probabilities of kill it is possible to analyse particular weapon choices and topside locations against different attack scenarios. This analysis can be applied as it only requires the speed of the attacking/defensive missiles, probabilities of kill and arcs of coverage. An analysis can be run against the proposed topside model to aid the designer in his choice of weapons and their placement. The only impact it has on the overall proposed design system is on data in the database to enable the analysis to be run.

The basis of the analysis is to define the topside layouts under consideration and then to define a series of threat scenarios[82]. The designs can then be measured against their ability to engage and destroy the incoming threat missiles and modifications made to the layout if necessary. For full reference the exercise notes should be consulted [Bayliss 96], [MIT 96][83]. Presented here is a summary of the process. The solution process consists of five stages (a - e) that are discussed in the following

[82] The threat scenario defines the attack scenario in detail. It gives information on the attack weapons and the timing and location of the attack. This is most likely to be the type, speed and number of threats with their locations at time = 0s for the scenario. A single topside configuration can be assessed against multiple threat scenarios or a single threat scenario can be used to assess different topside designs.

[83] [Bayliss 96] is a topside design exercise, run by the author, as part of the M.Sc. Naval Architecture course at University College London. This exercise was developed using the "Surface Ship Combat System Design Integration" Summer school course run by MIT as a basis [MIT 96].

paragraphs (Figure 7.5). Selection of systems is carried out before placement and resulting coverage is determined. The arrangement is then measured against a threat, reaction times calculated and associated probabilities of kill determined. The arrangement can then be refined and results recalculated.

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Figure 7.5 : Exercise Solution Process [MIT 96]

a) Select Candidate Systems

This is the first stage of the process where choices are made as to which systems are to be investigated. In order to make these choices some details are required on both the scenario type and the weapon systems themselves. For a simplistic analysis it is only possible to consider one type of scenario at a time, therefore it is necessary to define the aim of the particular scenario. Examples of the types of scenario are a self defence role, attacking role or protection role. For whichever type of scenario is chosen it is necessary to define the threat. This has to be done in terms of number of threats, threat position, speed and attack profile of the enemy.

Once the scenario type[84] has been defined it is then necessary to choose equipment suitable to the task. Details are required on available systems in order to allow informed choices to be made. It is important to consider this choice in isolation from

[84] For example, self defence against missile attack, self defence against aircraft.

the threat scenario[85] defined to ensure choices are not made based upon knowledge of the scenario. The details required are show below:-

Weapon Type	–	The type of weapon, for example, offensive, defensive, terminal defence.
Cost	–	To allow cost trade-off studies to be performed.
Equipment elements	–	Requirements for separate tracker/detector systems.
Detection Range	–	The maximum range at which the equipment can detect the enemy.
Interception Range	–	The range at which the weapon can engage the enemy.
Operation Details	–	Whether the system is missile based or gun based and for each, the weapon firing times, or missile launch characteristics.An example missile philosophy may be to fire two missiles in a salvo separated by a particular time and then wait for kill assessment before firing further missiles.
Reaction Time	–	This is the time taken by the system to react to a new target, and be in a position to open fire. This time is made up of the time required for the tracking radar to acquire the target and the weapon system itself to train to the target bearing and be primed ready to fire.
Kill Assessment	–	This is the time taken by the system to assess whether the target has been killed.
Probability of Kill	–	The probability that the weapon system will kill the enemy.
Weapon Restrictions	–	Any further restrictions such as the number of available missiles, or limitation on the number of systems that can attack a single target.

[85] Although the type of scenario is defined to allow choice of suitable weapon systems the specific details of the threat must not be considered until later in the scenario evaluation. Having knowledge of the threat scenario would cause the naval architect to bias the solution to countering the defined threat scenario rather than the type of scenario.

Using this information a choice can be made to meet the postulated scenario. This has to be done by the naval architect by considering the possible threat and the weapon systems and defensive measures available. Judgement has to be used but many different combinations of weapon systems and configurations can be evaluated if the naval architect is unsure as to which system may perform the best[86].

b) Determine Combined Coverage

The chosen systems need to be arranged onto the ship topside in order to determine the coverage for the systems. This exercise can be carried out using a simple general arrangement drawing of the ship superstructure. Coverage diagrams (Figure 7.6) can be constructed for each type of weapon system to show the combined coverage that is obtained. This coverage is a three dimensional coverage but for an indication it is sufficient to present coverage at a zero degree elevation. This will highlight any shortcomings in the arrangement and allow for modifications to be made.

Figure 7.6 : Sample Coverage Diagram [Bayliss 96] [87]

These coverage diagrams need to be constructed for each weapon system chosen. Where a system consists of trackers and launchers this information should all be

[86] The scenario modelling approach provides a good method to evaluate different weapon systems, providing some indication of which systems perform better than others.

[87] Whilst Figure 7.6 is taken from [Bayliss 96] the generation of a coverage diagram is a common technique and further details can be seen in [Mangulis 79], [MIT 96], [Skarda 98]. The diagram can be enhanced to show maximum and minimum engagement ranges where they are applicable. This is most likely necessary in the case where a close in weapon system is limited in elevation around the azimuth when attempting to fire at a sea skimming incoming threat missile close to the ship [MIT 96].

combined onto a single plot to show the coverage for the entire system. It is in this phase of the process that the blockage models (BAM) discussed in Section 7.2.1 would be used.

c) Determine Reaction Times

The reaction times are calculated through knowledge of the threat and the weapon systems placed on the ship. Speed, distance and time calculations can be carried out to calculate the possible firing solutions available to the ship. For the threat it is possible to allocate particular weapon systems and calculate the times at which they need to fire to engage the targets. Use can be made of the coverage diagrams to ensure the threat is within the coverage of a particular system. It is important to consider the reaction times[88] and kill assessment time[89] within these calculations to ensure the fire times remain realistic.

An example of this type of calculation is shown in Figure 7.7. In this particular example the incoming threat is travelling at 270m/s and the defensive missile (NSS) travels at 420m/s and has a maximum engagement range of 19000m. Consideration has been given to the radar horizon assumed to be at 36100m. The reaction time for the system is 12 seconds and the kill assessment takes 6 seconds.

Calculations of this type are required for all available systems and threat combinations. The situation is further complicated when reallocating systems after they have been used once. It is important to ensure that the timings are consistent with that achievable. It is not always possible to engage at maximum range or for the desired amount of time.

Once the overall timing calculations have been carried out the designer has to decide which weapon will be used to engage which target and when. In effect the designer is acting as a simple command system prioritising the engagement of the threat.

[88] This is the time required by the system to react to the threat, train to the bearing if necessary and be ready to fire.
[89] This is the time taken by the system to evaluate whether the defensive measure has been successful.

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Figure 7.7 : Example Time Line Calculation [MIT 96]

d) Determine Probability of Success

From the previous stage in this analysis the complete engagement has now been defined. It is now possible to apply simple probability to provide a final indication as to the suitability of the weapon choices and arrangement. For each threat the engaging systems are known and the timing and number of engagements made has been calculated.

The probability of at least one threat being successful can be calculated by considering the systems employed to defeat it.

The probability that at least one of the defensive systems (A, B and C) will be successful against the threat is defined as:-

$$1-[[1-P(A)]\times[1-P(B)]\times[1-P(C)]] \qquad \textit{Equation 7.4}$$

Where : *P(A)* : probability that system A is successful

P(B) : probability that system B is successful

P(C) : probability that system C is successful

This analysis can be extended for as many systems are used.

It is now necessary to calculate the probability of kill associated with the type of weapon system used.

If the ship's weapon type is missile based and the defence consists of a number of missiles fired at the incoming attack, and each missile has an assumed probability of killing the target, then overall probability is defined as:-

$$Pk(overallM) = 1 - (1 - Pk(missile))^n \qquad \textit{Equation 7.5}$$

Where : *Pk(overallM)* : overall probability of kill for the missile system

Pk(missile) : individual probability of kill for an individual missile

n : total number of missiles with which the target is engaged

If the defensive weapon type is gun based and the defence is defined by a period of time spent firing at the enemy, then this period depends upon the speed of the attacking missile and the ranges at which engagement is possible. The overall probability is a function of this time and the cyclic rate of fire for the gun system and is defined as:-

$$Pk(overallG) = (Roundsfired) \times (Pk(Singleround)) \qquad \textit{Equation 7.6}$$

Where : *Pk(overallG)* : overall probability of kill for the gun system

Roundsfired : number of rounds fired in the engagement

Pk(Singleround) : individual probability of kill for a single round

Further systems could be defined consisting of decoys and jammers where a simple probability of soft kill can be defined as a single figure[90], or models developed for each case.

Using the equations defined above it is possible to calculate the probability that the threat will be killed by one of the measures employed against it. Where the scenario consists of several threats this is done for each threat and the results combined to calculate the probability of one of the threat being successful.

$$P(ThreatSuccess) = 1 - (P(T1)) \times (P(T2)) \times (P(T3)) \quad \textit{Equation 7.7}$$

Where : *P(Threat Success)* : probability of at least one threat being successful

P(T1) : probability of killing threat 1

P(T2) : probability of killing threat 2

P(T3) : probability of killing threat 3

This analysis can be extended for the number of threats in the postulated scenario.

This simple probability based analysis can be employed for a variety of threats and equipment arrangements. The final figure provides a good indication of the performance but the real benefit of the exercise is in the understanding gained of the particular systems against the threats. This can highlight situations where another system may clearly perform better. This allows informed decisions to be made because the analysis can expose weak points in the systems chosen that may not be immediately apparent when selecting and arranging the systems. One such example is in the choice of gun based systems where the importance of a high fire rate is clearly demonstrated against high speed targets. Differing systems may have widely different probabilities of kill for a single round but when considering the overall operation it becomes clear that it is a function of the single round probability and the

[90] Unlike ESM equipment that generally fits beneath the main radar with 360° coverage, jammers often have to be fitted in pairs to give 360° coverage. Four or more decoy launchers are often required to give 360° coverage. A single figure for probability of kill can be assigned for these soft kill systems [Bayliss 96], [MIT 96]. This implies that these systems will have a fixed probability of countering the attack.

rate of fire that determine the overall probability of kill. Therefore the choice of the system with the highest probability of kill per shot may not necessarily be the most suitable choice. Threat scenarios can be designed to test these particular aspects using different expected threats.

Such analysis shows a method of evaluating differing topside arrangements against an envisaged threat. The process is clearly simplified and the actual figures depend upon accurate weapon information. However as a method of comparing alternatives it is useful. The one possible shortcoming of this simple modelling approach is the accessibility of data. Clearly this information is militarily sensitive and as such no effort has been made in this thesis to reflect accurate values. The use of the methodology is demonstrated, if accurate results are required for a final system weapon manufacturers and operational analysts would have to be consulted to compile suitable values for real ship systems. At the early stages of design the aim is to identify significantly different performance between alternatives and the proposed method should allow suitable choices to be made. If systems have similar capabilities then other aspects such as cost, ship impact and operational flexibility may have a greater impact on the choices made by the naval architect.

7.3.2. Application of the Approach

The application of this approach has been investigated through an exercise designed for use as part of the UCL M.Sc. Naval Architecture topside design course at UCL [Bayliss 96]. The students were divided into groups and provided with information on weapon systems[91] and details of the ship[92] on which to place the systems. Details were provided on the weapon systems shown in Table 7.2.

[91] This information was highly sanitised and the provided probabilities of kill did not reflect actual values [Bayliss 96].

[92] A General Arrangement (GA) of the ship topside was provided with suitable locations marked. For each of these positions the students were provided with a BAM to allow rapid generation of coverage diagrams [Bayliss 96].

Equipment Type	Equipment[93]
Soft Kill	Electronic Countermeasures Decoys
Small Calibre Guns	.50" Machine Gun 25mm Machine Gun
Close in Weapon Systems (CIWS)[94]	Phalanx Goalkeeper
Missile Systems	Seasparrow (vertical launch silo with trackers) Seawolf (trainable launcher and tracker) Rolling Airframe Missile (RAM) (trainable launcher)

Table 7.2 : Scenario Modelling Exercise Weapon Systems, derived from [Bayliss 96]

Weapon systems and locations were chosen and coverage diagrams prepared. This part of the exercise was carried out before the threat scenario was revealed. Time line calculations were then carried out and weapon allocations made. Probability analysis was then used resulting in a final figure of expected number of hits on own ship.

The requirement was to:-

Select and locate combat subsystems

to provide anti-surface missile self defence

This had do be done subject to the following requirements:-

- Provide two or more layers of self-defence where a layer is a close in weapon system (CIWS) or a missile system.
- Each layer must provide 360° coverage.

[93] The equipment descriptions provided were based on current weapon systems [Hooton 98] and the names retained to add reality to the exercise. Those familiar with the system would have an immediate understanding of the mode of operation.

[94] Close in Weapon System (CIWS) - Automated rapid fire machine gun systems designed as a close in last ditch attempt to shoot down the incoming missile [Hooton 98].

- The overlap within each layer must be maximised.
- Ensure the ability to track and engage sea skimming missiles to minimum engagement range.

The threat scenario can be seen in Figure 7.8. For all of the student groups the constraints on the exercise and the time available[95] were identical.

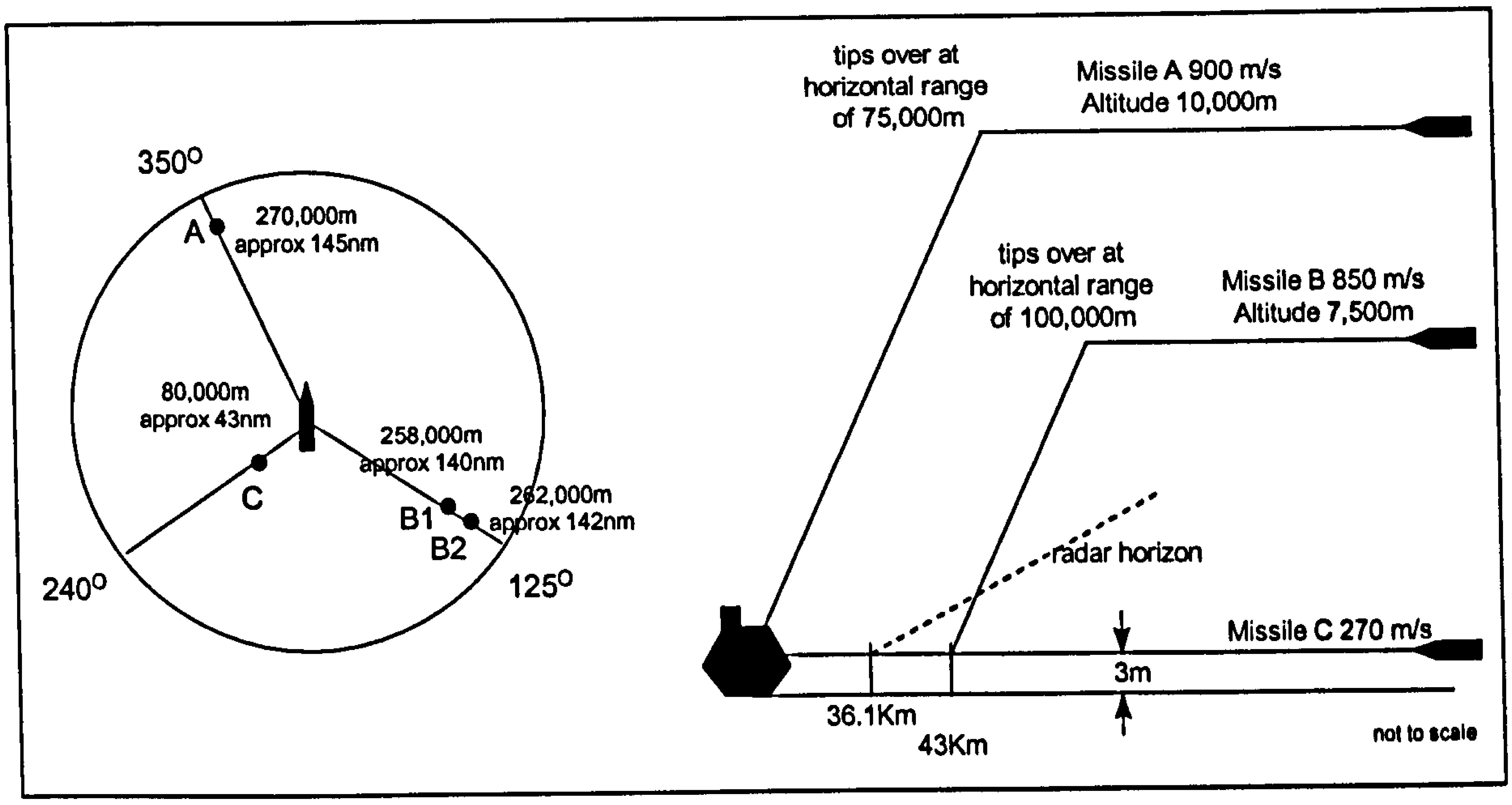

Figure 7.8 : Example Threat Scenario [Bayliss 96]

The results for this exercise carried out by several groups of M.Sc. students over four years are shown in Table 7.3. Details are provided of the type and number of the major chosen weapon systems and the results of the final calculation for the probability of at least one hit on own ship. The nature of the exercise resulted in many different configurations and no same configuration was produced in one single year[96]. The many different topside configurations are not reproduced within this thesis.

[95] The exercise was run for four years (by the author) as a one day exercise as part of the Naval Architecture M.Sc. lecture programme. The choice of weapons, and the coverage diagrams were prepared in the morning. The threat scenario was revealed in the afternoon and the time line and probability calculations carried out.

[96] The exercise was run ensuring different configurations for each group. This allowed a wider discussion after the process as all weapon systems would have been used and some teams forced to use what they initially felt were less suitable positions on the topside.

Year and Group	Chosen Configuration (number of systems)					Probability of at least one hit on own ship
	Vertical Launch Sea Sparrow Directors	Seawolf Systems	RAM	Goalkeeper	Phalanx	
1996 Grp 1	2	-	2	-	2	0.016
1996 Grp 2	3	-	1	2	-	0.014
1996 Grp 3	4	-	-	2	-	0.029
1996 Grp 4	2	2	-	2	-	0.007
1996 Grp 5	3	-	1	-	3	0.026
1997 Grp 1	2	-	1	-	4	0.119
1997 Grp 2	4	-	-	-	4	0.187
1997 Grp 3	-	2	2	1	1	0.055
1998 Grp 1	2	-	1	-	5	0.144
1998 Grp 2	2	-	1	1	-	0.006
1998 Grp 3	-	1	3	-	2	0.046
1998 Grp 4	2	-	2	-	2	0.001
1998 Grp 5	2	-	-	4	-	0.157
1999 Grp 1	2	2	-	-	3	- [97]
1999 Grp 2	3	-	1	-	3	0.019
1999 Grp 3	2	1	1	1	1	0.034
1999 Grp 4	2	-	2	-	2	- [97]
1999 Grp 5	2	-	1	2	2	0.162

Table 7.3 : Probabilities of at Least One Hit on Own Ship

This exercise illustrates a method of evaluating differing topside arrangements against an envisaged threat. The process is clearly simplified and the absolute figures depend upon accurate weapon information. In this specific case the numerical answers obtained are very low and this is due to the assumptions made by the teams

[97] No result produced within the time available.

and the provided probability of kill values assigned to the weapons being too high. Accurate figures were not used due to the classification of such information and the values assigned are not likely to accurately reflect the actual weapon performance, more likely overestimating the probability of kill. However as a comparative exercise the applicability of the method has been illustrated. Although the calculations were performed rapidly by the student teams the results show a spread of probabilities as a final outcome. It was expected that solutions with only two layers of defence as opposed to three may perform less well with a four missile threat and this was proven to be the case. A three layer defence consists of either Seawolf or Seasparrow providing long range defence, RAM providing mid range defence and either Phalanx or Goalkeeper providing inner layer defence. A two layer defence has only two of these elements. Some groups implemented Seawolf and Seaparrow providing two layers of longer range defence. Two layer defence was used by only three groups, 1996 Grp 3, 1997 Grp 2 and 1998 Grp 5. The probabilities from the later two of these are the highest from the exercise. The result from 1996 Grp 3 is lower, but not amongst the lowest obtained. This type of analysis also allows investigation of different threat missiles, such as the comparison between subsonic and supersonic missiles allowing a measure of different effectiveness to be gained [McEachron 97].

Through this process the difficulty with which the task was undertaken is shown. Although based around simple time line calculations and basic probability many errors were made requiring re-work as the calculations progressed. The exercise takes over six hours to complete for a single configuration and threat scenario. In some cases the exercise was not completed within the time allowed, the students often became confused about which weapon to allocate when and the implications this would have on the remaining calculations and overall outcome.

Although demonstrating the suitability of this type of analysis for inclusion in the proposed tool clearly there is a need to computerise the calculation procedure to allow analysis to be undertaken in minutes rather than hours. This computerised approach would also avoid calculation errors. The approach adopted must not be a 'black box' solution and the designer must have full visibility of the assumptions made and the calculations performed.

7.3.3. Computerised Analysis

In order to automate the methodology it was implemented on a computer[98]. Simple spreadsheets were devised to undertake the exercise used at UCL but these were bespoke spreadsheets and only applicable to the particular threat scenario and weapon configuration chosen [Bayliss 98]. Work was carried out to identify the data requirements and calculation procedure required in order to develop a multi-purpose computer tool allowing analysis of any scenario based upon the methodology outline above. This work was continued, under the co-supervision of the author, as an M.Sc. project and resulted in a limited Weapon Arc Evaluation Program [Skarda 98]. The aim of this project was to take the work carried out and to use suitable computer languages to develop a workable computer tool. This was expected to highlight any shortcomings in the data requirements identified and also investigate the resulting presentation aspect of any proposed tool.

The program was developed using a combination of Microsoft Access[99] and Microsoft Visual Basic[100]. Microsoft Access was used to store the necessary data. The basis for this database was the data already identified through development and implementation of the exercise used at UCL [Bayliss 96] (Section 7.3.1). This database was added to where required as the code was developed and further data requirements were identified [Skarda 98]. The final database elements required for scenario modelling are shown at Appendix 6. This database defines the minimum information required to be held within the overall system database to allow simple computerised scenario modelling to be carried out.

[98] Various specialist computer programs have been developed implementing scenario modelling. These are often limited to particular types of scenarios or weapons and require detailed system information. Examples of computer code and the complexity of the input data required can be seen in the models used by QinetiQ (formerly DERA) with some simulations requiring input of 100's of values along with detailed ship and system data [Parkins et al. 96].

[99] Microsoft Access is the standard database tool supplied by Microsoft as part of the Microsoft Office suite of programs.

[100] Microsoft Visual Basic is a visual computer programming language, supplied by Microsoft, based around the BASIC computer code but enhanced to allow easy construction of dialogue boxes and display screens within a windows environment [Microsoft 97].

A flow chart of the resulting program operation is shown in Figure 7.9.

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Figure 7.9 : Weapon Arc Evaluation Program Flow Chart [Skarda 98]

It can be seen that a large proportion of the program is devoted to the handling of the data required to set up the scenario. The scenario calculations, resulting in a time line output, selection output and probability output, are only carried out after data input has been completed and validated, this was due to the program being stand-alone.

Within the proposed system topside design tool, the four selection boxes relating to the selection of sensors, gun systems, missile systems and EW systems would not be required as this data would already be captured by the overall topside system database. Similarly the input required for system co-ordinate and clearance/firing arc information would not be required as this would be calculated from the model already held in the topside design system. The role of the main selection page would be carried out within the proposed topside design tool as items are placed into the design space. The database requirements would be included in the overall database. Therefore the remaining elements would be those required as part of a system to be incorporated into the overall design tool. These are essentially a choice of scenario and validation of the elements before scenario calculations are undertaken and the results presented.

The output is threefold:-

Selection Output

This output file lists the selected systems, their co-ordinates and arcs. The details of the selected threat scenario are given.

Time Line Output

This file gives a time line readout for each weapon system. The header details the filename, the name of the ship, the name of the threat and the bearing at which the threat is approaching the ship. Results are then presented in a time step fashion detailing the weapon status at each period in time, from commencement to closure of given engagement.

Probability Output

This file is used to plot the probability of killing an assumed incoming missile. Results are recorded for each ship system as well as the overall calculation for a full 360° range of bearings. Calculations are carried out for each defensive system at 1° increments around the azimuth. Probability of kill is calculated for each of these and then averaged to provide a single mean value for the configuration [Skarda 98].

The system developed is limited in operation to a single incoming threat missile. This is due to the additional complexity required when multiple missiles are assumed to attack the ship. When this is the case, sensible weapon allocation has to be made and this would require ship command input. For a single missile threat it can be assumed that all defensive measures possible will be employed against the single incoming threat. If there are multiple missiles, as in the threat scenario seen in the exercise described earlier [Bayliss 96] a choice of weapon allocation has to be made. A suitable method within the program developed by Skarda was not identified during the M.Sc. project and the Weapon Arc Evaluation Program code, produced in 1998, does not simulate a multiple missile threat [Skarda 98][101].

7.3.4. Multiple Missile Engagements

When evaluating a multiple missile scenario numerous decisions have to be made on weapon allocation by the topside designer. The designer should be aided in the choice by the tool but not forced to adopt a single solution. The challenge is to present results in such a fashion that they are available to the designer as the scenario develops allowing choices to be made on weapon allocation, and providing immediate feedback of the implications.

The limitations of the method of result presentation adopted by Skarda are conveniently illustrated through a simple example, a single incoming threat and a single defensive missile system having full 360° coverage. This removes additional complications and produces a set of simple results. The major details of the attacking and defensive systems chosen for this example are shown in Table 7.4. Suitable sensors were added for calculation in the Weapon Arc Evaluation Program, a surveillance radar is required along with a tracker radar to guide the defensive missile. These sensors were placed artificially high to ensure they were operable for

[101] Skarda identifies several shortcoming with the code as developed and recommends improvements including the inclusion of an air search radar capability extending the radar horizon, more complex modelling of the EW systems, inclusion of the multiple missile scenario prompting the user to make weapon allocation choices when required, the ability to move the ship to the most effective bearing to counter the threat and including additional information on the missile flight trajectories [Skarda 98].

their maximum range rather than horizon limited to avoid complication. The range of the surveillance radar was 115000m and the tracker range was limited to 15000m.

	Defensive System Seawolf 32 Cell VLS	**Threat** MM40 Exocet
Missile Velocity	Mach 2.0	Mach 0.9
Maximum Range	6000m	-
Minimum Range	500m	-
Time between Launches	1.20s	-
Probability of kill per missile	0.36	-
Threat evaluation time	6.00s	-
Reaction time	3.00s	-
Kill assessment time	6.00s	-
Terminal attack altitude	-	3.00m

Table 7.4 : Details of the Example Threat and Defensive Systems

This arrangement was entered into the Weapon Arc Evaluation Program and results produced. The only way that the user can see how the scenario has developed is to consult the time line output. The results are presented in a time step fashion with 30 readings being displayed for each second of the scenario resulting in over 1500 lines of output from the time the missile is in range of the tracker radar to final impact. This number of lines of output would be far greater for a system having a greater range than the Seawolf system used in this example. This resolution is required to ensure accurate timings are presented for all events. It can be argued that this full output is not required and can be condensed down to show only those times at which a change of state occurs. This would produce output as shown in Table 7.5. Although far more concise, this form of output would become increasingly confused if it were to also show results for additional weapon systems. Additionally it is difficult to picture how the scenario would develop as there is not a constant time step. In order to picture what is happening in the scenario, the designer has to have knowledge of the incoming missile speed and range and the status of the defensive systems, which missiles are in flight and their remaining range to intercept. Whilst for the example presented here it is not difficult to understand the timeline output, if this were to be extended to include additional incoming threat missiles and an increased number of defensive systems then the level of complexity would greatly increase. Even in the reduced format presented here the topside designer would have a considerable task in analysing the data to understand the output.

Time Index	Threat Range	Gun System 1-4	Missile System 1	MissileSystem 2-4
51.355	15252.4383		Out of Sensor Rng	
50.5217	15004.9383		Out of Sensor Rng	
50.4883	14995.0383		Threat Assessment	
44.5217	13222.9383		Threat Assessment	
44.4883	13213.0383		Reacting	
41.5217	12331.9383		Reacting	
41.4883	12322.0383		Out of Range	
29.3217	8708.5383		Out of Range	
29.2883	8698.6383		Launch Missile	
29.255	8688.7383		Ready Next Round	
28.1217	8352.1383		Ready Next Round	
28.0883	8342.2383		Launch Missile	
28.055	8332.3383		Missile in Flight	
20.2217	6005.8383		Missile in Flight	
20.1883	5995.9383		Missile Detonation	
20.155	5986.0383		Missile in Flight	
19.3883	5758.3383		Missile in Flight	
19.355	5748.4383		Missile Detonation	
19.3217	5738.5383		Kill Assessment	
13.3883	3976.3383		Kill Assessment	
13.355	3966.4383		Launch Missile	
13.3217	3956.5383		Ready Next Round	
12.1883	3619.9383		Ready Next Round	
12.155	3610.0383		Launch Missile	
12.1217	3600.1383		Missile in Flight	
9.2217	2738.8383		Missile in Flight	
9.1883	2728.9383		Missile Detonation	
9.155	2719.0383		Missile in Flight	
8.3883	2491.3383		Missile in Flight	
8.355	2481.4383		Missile Detonation	
8.3217	2471.5383		Kill Assessment	
2.3883	709.3383		Kill Assessment	
2.355	699.4383		Below Min Range	
0.0217	6.4383		Below Min Range	

Table 7.5 : Reduced Time Line Output

The shortcomings of a time step based output format can be readily seen, not only are large amounts of output produced, this output is also not immediately self explanatory and requires careful analysis for full understanding. If comparative tests are to be undertaken it is not immediately apparent as to the difference between each scenario. The Weapon Arc Evaluation Program also performs a 'black box' type calculation. The input parameters are fed in and the calculation performed before results are produced for analysis. It is this sequential approach to calculation that hinders the implementation of the necessary user input required to allow choices to be made for multiple missile scenarios as the engagement progresses. The requirement to make weapon allocation choices requires the designer to be able to picture the scenario as it is developing and to have feedback on the implications of the choices being made.

Due to the simplifications made in the scenario modelling process proposed, where constant velocities and target missiles coming directly towards the ship are assumed, the data can be presented using a simple range/time graph [MIT 82][102]. This has been done for the example scenario defined (Appendix 7) and the results are shown in Figure 7.10. All missile profiles are described by straight lines which are mathematically defined and manipulated.

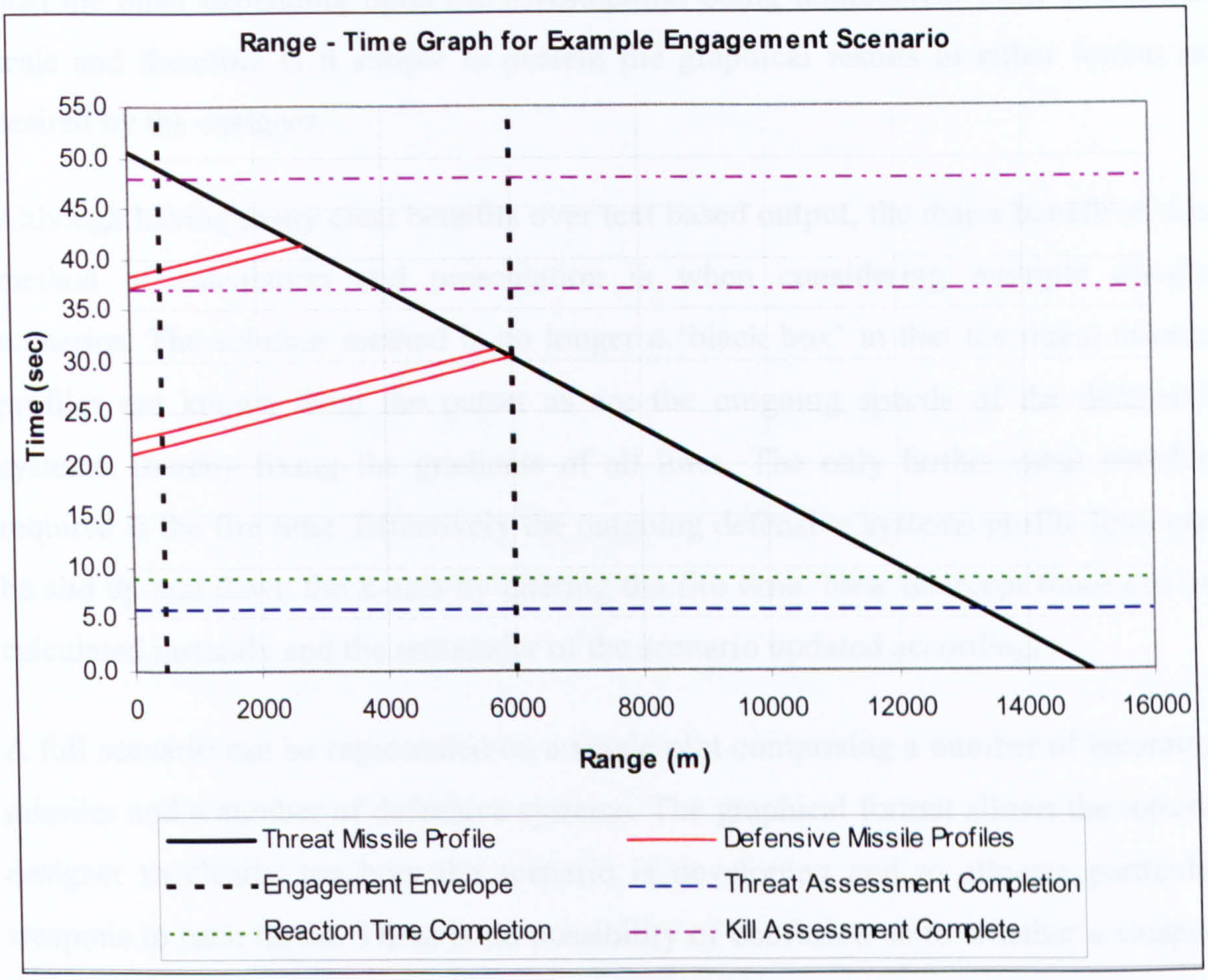


Figure 7.10 : Range -Time Graph for Example Engagement Scenario

From this single figure it is apparent that four missiles have been fired with the first engaging the target at the maximum range. The range of detection of 15000m is seen to be sufficient against this threat as the threat assessment and reaction time do not

[102] Constant velocity missiles result in the simplest form of the Range – Time Diagram. Varying velocities can be catered for but do not result in a single straight line on the plot. This graphical method also allows the presentation and engagement calculation for crossing targets [MIT 82].

limit the engagement. The effect of the kill assessment time is shown, as is how this limits a third salvo being launched. Although there is no more data presented on the figure than captured in the output from the Weapon Arc Analysis Program the presentation is far more easily interpreted.

The timescale used in the presentation of the range time graph is different to that in the time line output with Figure 7.10, placing a value of zero time for the start of the scenario. The Weapon Arc Evaluation Program assumes a value of zero time when the threat missile reaches the ship. Each is equally valid and one may be more use than the other depending upon the investigation being undertaken. Time is a linear scale and therefore is it simple to present the graphical results in either format as desired by the designer.

Although having many clear benefits over text based output, the major benefit of this method of calculation and presentation is when considering multiple missile scenarios. The solution method is no longer a 'black box' in that the threat missile profiles are known from the outset as are the outgoing speeds of the defensive systems, thereby fixing the gradients of all lines. The only further input variable required is the fire time. Effectively the outgoing defensive systems profile lines can be slid up and down the x-axis by altering the fire time. New intercept times can be calculated instantly and the remainder of the scenario updated accordingly.

A full scenario can be represented on a single plot comprising a number of incoming missiles and a number of defensive systems. The graphical format allows the topside designer to clearly see how the scenario is developing and to allocate particular weapons to each threat. There is no possibility of confusion as to whether a weapon is already allocated or free to fire. This can be seen in Figure 7.11 where the example has been extended to include a second threat missile 20 seconds after the first. In this case the first two defensive salvos are the same as in the first example but it is clearly seen how the weapon can be reallocated, once threat assessment and reaction time are complete, to engage the second target with a salvo of two missiles. No further defensive salvos are possible as once the threat assessment is completed then the offensive missile is no longer in the engagement envelope. It can also be seen how this is not the only solution and clearly the defensive system could be assigned to engage the second target with the second salvo. The effect of this would be immediately calculated and fed back to the user.

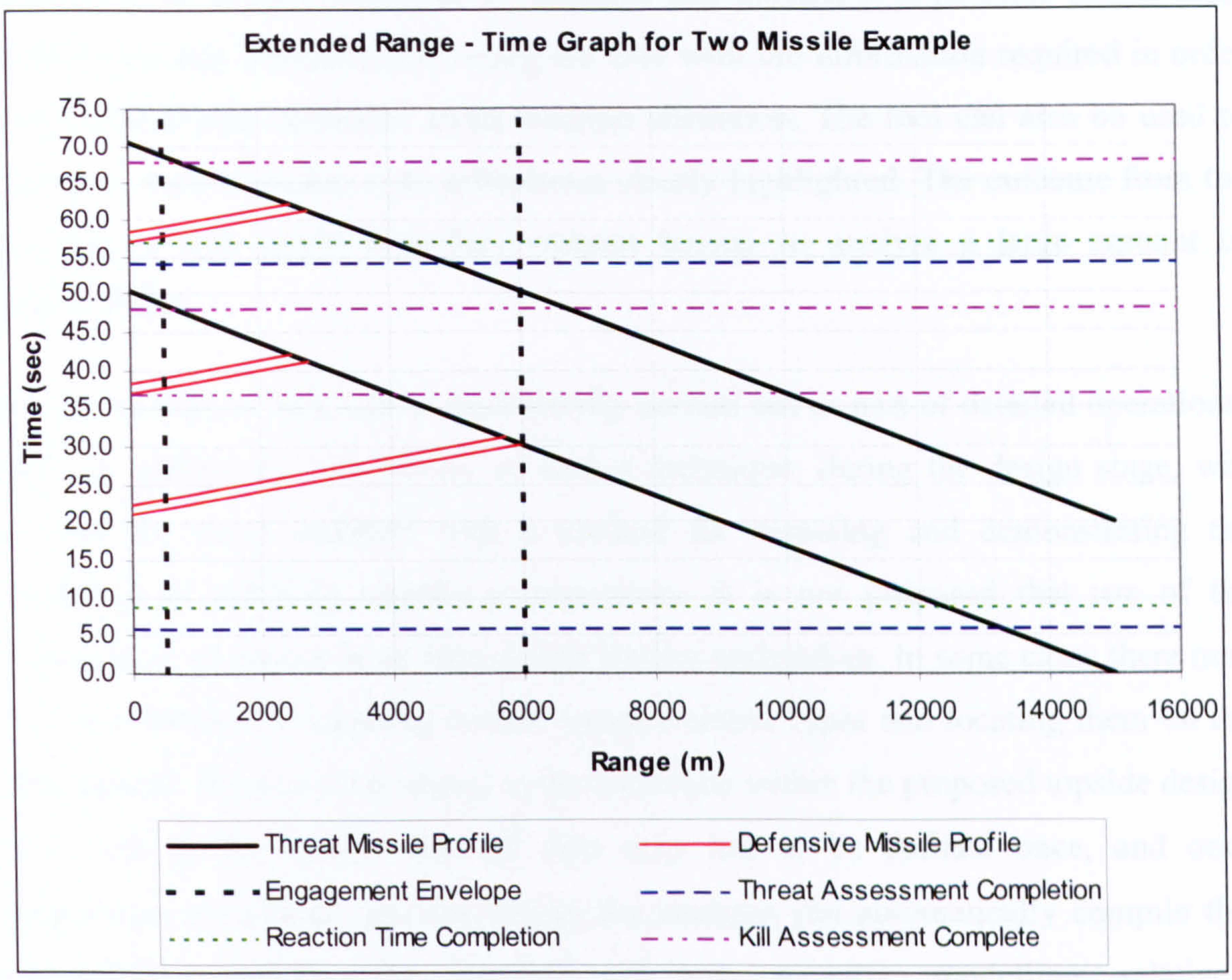


Figure 7.11 : Extended Range - Time Graph for Engagement Scenario (Two Offensive Missiles)

Further defensive missiles and incoming targets can be plotted on the graph providing a simple picture of the overall scenario. This is not limited to the type of defensive system used in this example. The method is equally applicable to all weapon systems and can easily handle those where multiple missiles can be controlled from a single radar or tracker, and those requiring no further guidance once launched. All that is required is an indication of weapon and tracker availability. This might be a single missile launcher and tracker system firing a salvo of two missiles, as shown in this example case, or the complete silo of missiles if a Vertical Launch System[103] is used. In the example case shown in Figure 7.11 if a defensive system is available with multiple channels of fire this could be used to

[103] There will be a required delay between launches from a VLS to ensure that efflux and debris from missile launch does not impact on the launch of others [MIT 96].

launch multiple missiles at both threat missiles simultaneously, allowing engagement at maximum range, this can be accommodated in the graph. Modifications can be made and the impact clearly seen. Through this method it is possible to allow for multiple missile scenarios, providing the user with the information required in order to make informed decisions about weapon allocation. The tool can also be used to carry out what-if studies with differences clearly highlighted. The outcome from the scenario is also easily described without having to analyse a large amount of tabulated data.

Whilst analysis of this type is traditionally carried out as part of detailed operational analysis studies, the availability of such a technique, during the design stage, will provide the naval architect with a method for assessing and demonstrating the suitability of differing topside arrangements. It is not proposed that use of the technique is necessary in all ship design studies undertaken. In some cases there may be clear reasons for adopting certain weapon/sensor types and locating them on the ship topside. By providing access to the technique within the proposed topside design tool there is the benefit that all data only has to be defined once, and once equipments are placed into the design the analysis can automatically compile this information, making the running of any scenario modelling relatively straightforward. This means that the designer is free to make the choice as to whether the running of a scenario modelling case would aid in the development of the design.

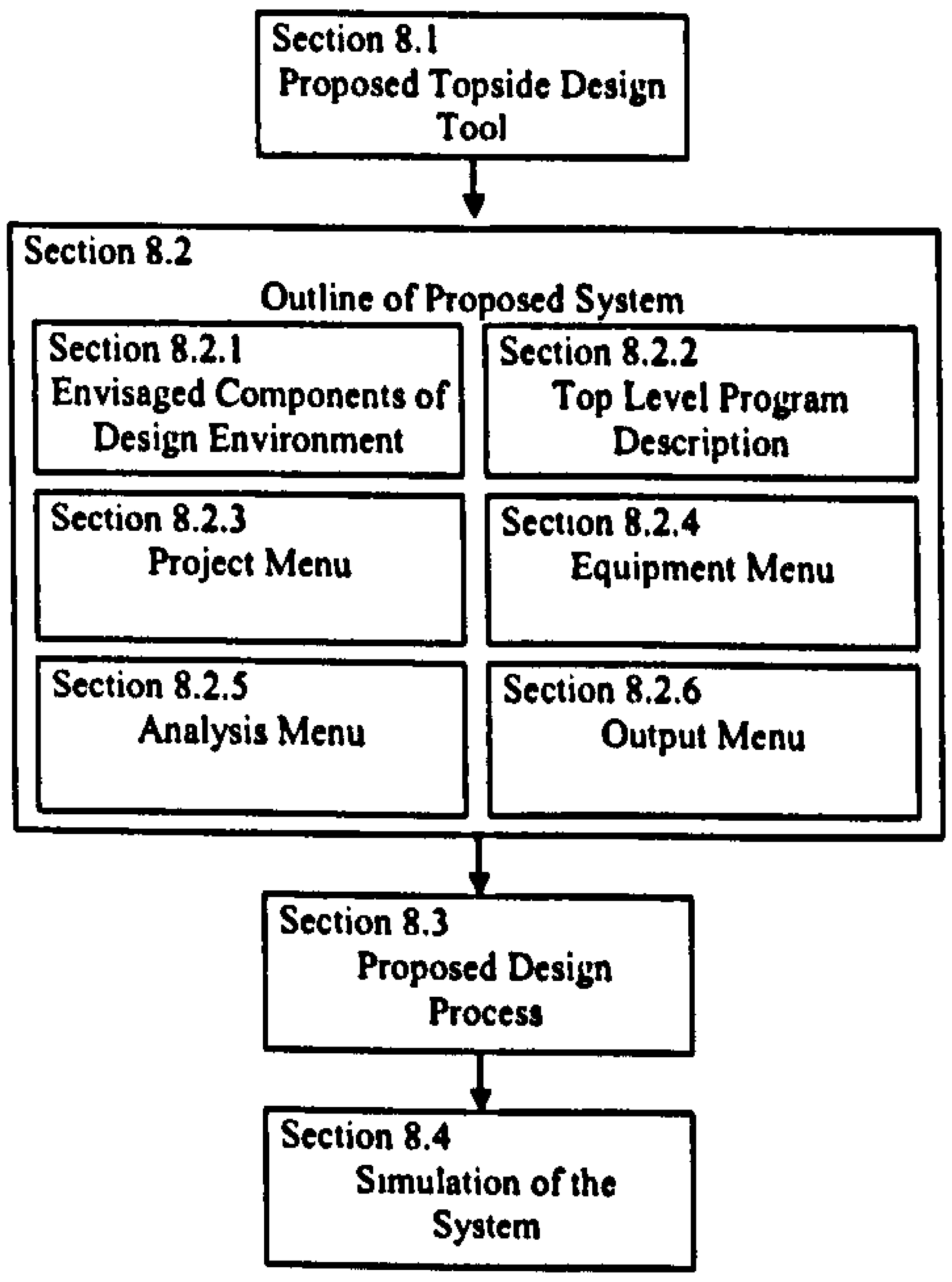
7.4. Conclusion

This section has introduced a variety of methods available to assess weapon arcs and weapon layout. The simple graphical display of blockage assessment models (BAM) is clearly informative to the user and can be generated from the geometry already defined in the model as it develops. It is proposed that a display of this BAM is available to the user for all equipment items placed into the design space.

Two methods have been proposed for assessing the suitability of the arrangement, the first is a simple analysis of whether a particular set of arcs is more suitable than another [Mangulis 79]. This calculation is not complex and draws upon the arc information already calculated for the BAM models. The inclusion of this simple tool will allow an assessment to be made of the arcs with an immediate feedback to the user of a figure of merit. Scenario modelling is also presented, the applicability of the method has been proven, however the presentation of results from the Weapon Arc Evaluation Program developed by Skarda [Skarda 98] has several shortcomings. The calculation of the overall probability, calculated by considering the threat at 1° increments of azimuth, is a useful measure system effectiveness. Graphs can be produced for single system effectiveness, and total ship effectiveness allowing easy comparison between differing solutions. This technique provides a good indication of the effect that blockage has on the total topside arrangement but is limited in application to single threat missile scenarios. This is due to the need for user input to allocate weapons to differing threats and so an automated process is not appropriate. To facilitate multiple threat missile scenarios it is proposed that the methodology be implemented through the use of range time diagrams. This will enable multiple missile scenarios to be investigated with results displayed on screen, rather than as a large amount of printed data. Use of the clearance/firing arc data will limit which weapons are available for each missile within the scenario.

By providing these tools to the naval architect as part of the proposed topside design tool many differing analyses can be undertaken. The analyses to be run are not dictated by the design system and suitable investigations can be readily carried out by the designer. For a simple design it may just be necessary to make use of the BAM to ensure that suitable coverage for each system is provided. For more extensive design investigations there is likely to be a range of differing solutions to be investigated. Using weapon arc analysis and scenario modelling enables reasonably complex studies to be undertaken. There is no set procedure for using these tools, rather their use should be governed by the problems experienced in a particular design. A simple comparison of differing topside layouts can be carried out using a series of single threat missile engagements, using different threat missiles, assessed around the azimuth. This would give an indication as to whether there are any obvious shortfalls in the options. For more detailed study of the proposed topside weapon selection and associated layout, the more complex multiple threat missile scenarios can be used, providing a more realistic representation as to how the systems might perform. By considering a number of different threat scenarios different layouts and systems can be investigated and understanding gained on their advantages and disadvantages. The aim of the techniques proposed is not to provide an exact answer, if the results from any analysis do not clearly indicate one option being better than another then other issues such as cost, ship impact and overall risk to the project may be more relevant. Use of the proposed techniques will provide the designer with additional insight into the various design options under investigation and allow a greater understanding of their possible advantages and limitations.

8. PROPOSED COMPUTER AIDED TOPSIDE INTEGRATION TOOL



8.1. Proposed Topside Design Tool

Three major elements of the proposed topside tool have been introduced, EMC and EMI, stealth and signature control and finally weapon coverage and scenario modelling. Methods of incorporating design guidance into the envisaged topside design tool for these three major aspects have been outlined. This outline of the proposed topside design tool shows how these elements are seen within the proposed framework and how a designer might use it to explore individual components of a design solution. This chapter expands on the information presented in Chapters 3 and 4, with the knowledge gained from the investigations described in Chapters 5, 6 and 7 a more defined tool can be outlined. This proposed tool is a framework into which all further tools and methodologies can be incorporated.

The aim of the research described is to produce the definition of a tool that will aid the designer in the early stages of warship design (Section 1.1). As the design progresses the level of detail required increases, the proposed methodology should therefore be implemented in such a manner that application is not limited to these early phases. The computer model and analysis can be used for further work as the design progresses into higher levels of definition [Muñoz and Forrest 02]. The computer model should not become redundant after concept design but could be used as the design progresses or be exported[104] to more complex analysis tools[105]

All topside design work using the proposed design tool would be carried out within the graphical environment (Figure 8.1). This environment consists of a three dimensional space in which the upper deck, superstructure and equipment items can be placed. The designer will have access to a database of previous equipment items and the ability to enter further definitions for new equipment. Within this environment the designer will be able to pick up items and place these into the

[104] It is envisaged that the 3D CAD model will be exportable to other computer codes used in later stages of design. Although the modelling in the proposed tool will be fairly crude in comparison to a production model it will provide the initial geometry upon which more complex models can be based.
[105] The more complex analysis tools might be those previously discussed, such as detailed RCS and IR modelling (Chapter 6). However, as the design progresses there will be a need to export not only to detailed analysis tools but also to CAD systems allowing production level detail to be defined and production requirements planned.

overall design. The analysis and design guidance is made available to the designer either directly through the graphical interface or, for more involved analysis, through specialised output. The aim is a seamless design environment in which the designer does not have to become involved with the transfer of data or running of separate analysis programs. All control is maintained, by the designer, through the single consistent graphical interface.

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Figure 8.1 : Proposed Design System Elements [Andrews & Bayliss 98]

The proposed topside design system has two levels of operation, a broad level considering the major aspects[106] and a detailed level including all aspects of topside design. By splitting the approach into two levels it is possible to assist the designer by controlling the information requirements at each stage. Control over these two levels would be maintained by a project menu from within the top level program (Section 8.2). At the broad level the program will be limited to placing and analysing the effectiveness of major equipment items. The designer can then choose an appropriate stage at which to extend the analysis and include the smaller topside items.

The top level program consists of three major parts, firstly the overall graphical environment in which the operator works, secondly a menu system allowing the designer access to the facilities of the program, and finally an interrogative function.

[106] The major aspects would be limited to the main equipment items such as large superstructure blocks, uptakes and downtakes, main weapons systems and main sensors.

A more detailed breakdown of the program functions is given in Section 8.2. That section is not a detailed functional specification for the final system but is intended to show how such a system is envisaged to work within the computer environment. The program breakdown presented arose from an understanding of the appropriate types of tools and analysis. The submenu breakdowns presented in the figures (Figure 8.2-Figure 8.8) do not correspond directly to final menu items but rather indicate the areas that will be covered under each main menu item. The aim is to detail how such an integrated design environment will work within a computer system.

The varied set of analysis programs and facilities is intended to be tuneable by the designer so that specific problem areas can be considered without having to deal with the total topside environment at all times. The control of these programs is intuitive through the graphical environment and so the designer does not have to become involved with setting levels of detail or running external programs. If the graphical interface reveals the aspects in which there is concern, then the analysis available will correspond to this information. In this way the user is not presented with a multitude of analysis programs that may, or may not, be applicable to the questions or problem areas that are under consideration.

8.2. Outline of Proposed System

The proposed implementation of the methodology and the envisaged components of the design environment are discussed and the requirements outlined in this section. Sections 8.2.2 to 8.2.6 detail the structure of the proposed implementation. This is done by first considering the overall top level computer program before discussing the project aspects, equipment aspects, analysis elements and the program output. For each of these elements tree diagrams are used to illustrate how it is intended that the user will control the program and to highlight the proposed program structure.

8.2.1. Envisaged Components of Design Environment

In order to facilitate a system that can be used by the naval architect to allow topside integration aspects to be considered, various components are required in an overall suite of tools. The use of commercial software should be made wherever it is possible, as this software is externally supported and will reduce the amount of programming required for the new system. New computer code will be required in those areas where the analysis is new and to form the integration links between the various systems. This is similar to the development of SUBCON [Andrews et al. 96] and Paramarine [Paramarine 02] where standard graphics packages and programming languages are used.

Graphical Environment

The overall design environment for control and operation of the system is a graphical interface. This allows for visualisation of not only the physical geometry of the topside model but also graphical representation of interactions, clashes and other output obtained from analysis. The proposed system will use the graphical environment as the user interface and allow the designer freedom within it to investigate different designs.

In order to fully represent the topside environment it is important to model the arrangements as fully as is possible with the limited data that will be available. It is therefore necessary to have a 3D CAD system capable of handling complex 3D models made up from a series of smaller models. A full 3D solid modeller will allow for accurate representation and manipulation of all equipment items and superstructure within the computer environment and their manipulation. An attempt to model in 2D would not allow the user the interaction and immediate access and visualisation that is required. A 3D system using wireframe or surface models would be more suitable than 2D but limited in its ability to define and manipulate items with the ease that is possible within a solid modelling system. This is a similar approach to that adopted by the automotive industry [Howell 99].

Data Storage

The naval architect is not expected to be an expert in the many fields of engineering that are required to fully understand the complex interactions in the topside environment. As a result he will draw on a library of equipment items and characteristics that have been pre-defined or used in other studies. This information will require storage and interrogation by the user. A database system will allow for such storage with the additional benefit of defining the information that is required in order to fully describe the various types of equipment. This allows the user to then add further items of equipment, be they real or generic, and be aided in the definition by knowing what information is required by the system.

Data Manipulation and Analysis

It is envisaged that there will be various methods of analysis ranging from simple graphical clash detection to more complex modelling or interaction with an expert system. A suite of analysis programs will carry out this type of prediction and some simple calculations may be carried out by spreadsheet elements. More detailed analysis may require more complex computer programs but the important point to note is the interoperability of the systems chosen. The analysis programs must have access to the data held in the graphics system and further information in the database. The analysis programs must manipulate this and the output be presented in such a way as to integrate with the existing graphical environment. The integrated system should be transparent in its data transfer requiring no interaction from the operator other than the calling of a particular program. The final output should form part of the overall graphical environment in which the operator is already working. The aim of the proposed topside system is to present all information via the graphical window. Output should either be directly displayed on the 3D computer model, or within suitable additional windows where necessary.

Interface to Building Block Methodology

The proposed topside design tool is to form a companion system to the Building Block Methodology proposed by Dicks [Dicks 00] and now implemented in Paramarine [Andrews & Pawling 03], [GRC 03]. Both tools are based on a 3D graphical model with underlying analysis. It is important that an interface between the two systems enables the design work to be conducted in either tool as the design progresses. The Building Block Methodology is conducted in phases, initially starting with very crude weight and space definition at a Building Block stage which is then broken down into a higher level of definition at the compartment stage and finally an equipment stage [Dicks 00]. The proposed topside design tool will need to interact with the Building Block Methodology in the later stages. When decisions are being made about compartment and equipment layout, the results of topside analysis should be available. The database of equipment should be available through both systems, such that when considering the topside design, access is given to the tools proposed in this thesis. If the 3D CAD environment is the same for both systems the passing of the geometry data will be seamless[107]. The topside design tool requires equipment level definition and this will force the designer to consider some equipment items early in the Building Block design stage. This will require the decomposition of the major building blocks into compartment and equipment levels of details when required by the topside analysis. As the design progresses, the commonality of graphical elements and associated data will allow the designer to work within the Building Block Methodology or the topside design tool, passing information from one to the other, seamlessly, through the CAD interface.

8.2.2. Top Level Program Description

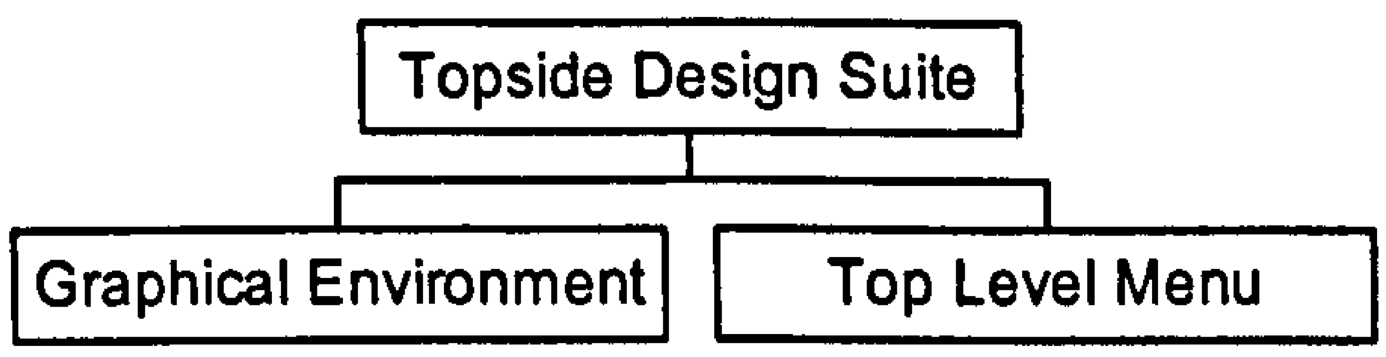

Figure 8.2 : Topside Level Program Description

The top level program consists of two parts, firstly the overall graphical environment in which the operator works, secondly a menu system allowing the designer access to the facilities of the program. This top level menu system will sit alongside the Building Block Methodology [Dicks 00]. The designer will have access to both tools as the design progresses and this interaction will be controlled by a higher level menu system allowing access to both the Building Block Methodology and the topside design tool and controlling the transfer of information between the two systems[108].

[107] The SURFCON system envisaged by Dicks [Dicks 98], [Dicks 00] has been implemented as a module, also called SURFCON, in GRC's Paramarine software [Paramarine 02], [GRC 03]. This module has been tested by the Design Research Group at UCL [Andrews & Pawling 03]. Detail has been given in Section 2.3.1.

[108] This thesis presents the proposed topside design tool, detailing the computer program structure required to complete the topside analysis. The use of a similar approach to that in the SURFCON Building Block Methodology will allow the development of an interface between the two systems once each has been developed as a separate entity.

Graphical Environment

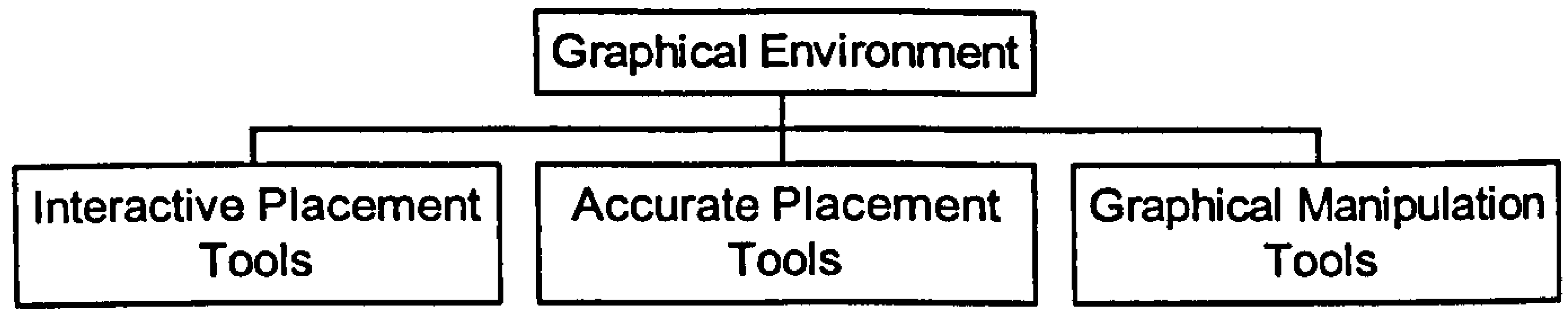

Figure 8.3 : Graphical Environment

All design work is to be carried out within the graphical design environment, and as such, all tools required for graphical manipulation are to be accessible from the desktop at all times. The envisaged scheme of operation is one in which the graphical interface provides the control over the design and provides information to the user. It should be possible to select all individual elements on the topside and position them as required. The positioning of elements and equipment items can be carried out by two methods. Firstly a drag and drop facility will allow the designer fast access to the design space and the ability to investigate the effect of changes very quickly. A second more accurate co-ordinate positioning system will allow for accurate placement of equipment items where constraints are known or the designer wishes to place elements in exact positions.

At the same time as allowing the positioning of graphical representations of equipment, the interface should allow the designer freedom to visualise the design as it progresses. In order to do this there must be the ability to control the graphical display. The ability to rotate and translate the design space in real time about the three axes allows visualisation of the design.

Top Level Menu

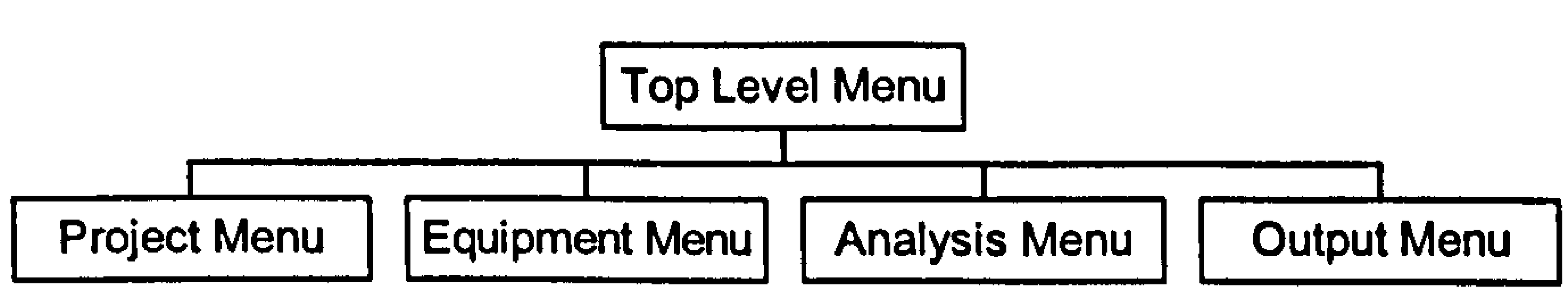

Figure 8.4 : Top Level Menu

Within the top level program, alongside the graphical interface will be the top level menu system allowing access to further facilities. It is through this menu system that the designer will have control over the information that is displayed and selection of the analysis programs. Sections 8.2.3 to 8.2.6 detail the menus and the facilities contained in each. The designer needs access to all facilities from these menus throughout all stages of the design. The analysis or display mode chosen will operate on the equipment and geometry defined within the graphical environment.

8.2.3. Project Menu

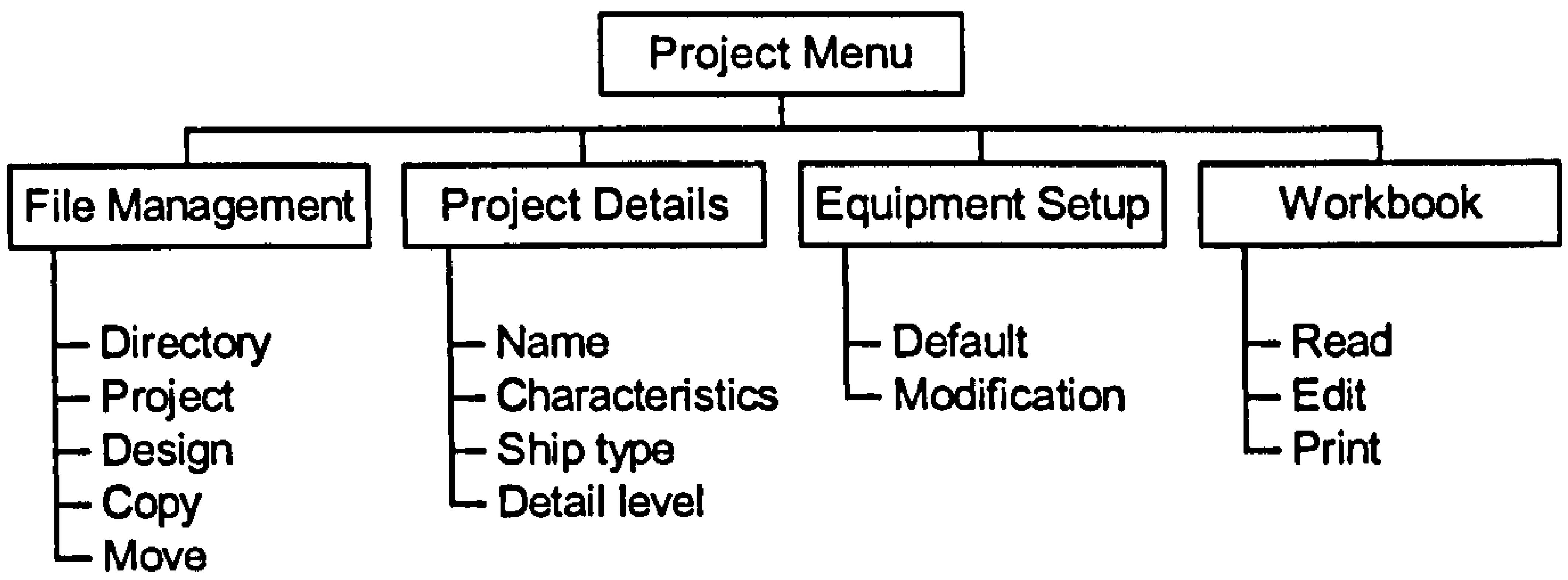

Figure 8.5 : Project Menu

The aim of this section of the program is to give the designer control over the project and to define within the system the type of ship that is being designed. This menu has four main roles.

File Management

This allows for the setting up of project directories and design directories and the copying of the designs within projects or between projects. It is through this that the designer can set up a series of similar studies within a project, by copying the original design and then making modifications, and also use past designs as the basis for a new study by copying into a new project from an existing one.

Project Details

This section allows for definition of the project details. It is envisaged that the following information will be required.

- Design name
- Brief description

- Approximate ship length, beam, draught and depth[109]
- Personnel requirement[109]
- Ship type (ASW, AAW, NGS, etc.)[109]
- Definition level

This information is then used to set up the design within the computer and allows for a crude representation of the deck area available and the freeboard[110]. This is then available to the graphics program for use in visualisation. It ensures that the design is bounded within reasonable limits. The definition of the personnel requirements enables the program to assess some of the measures taken by the designer and to ensure that they are appropriate. An example of such assessment may be the placement of life rafts, where the program, knowing the number of personnel, can ensure that a check is made against the number of life rafts carried to ensure that the Naval Engineering Standards (NES) [DEFSTAN 00] are met.

The definition of ship type is a design aid to the naval architect and will interact with the third part of this project menu, the equipment set-up. The definition level can be set by the designer and it should be possible to toggle between a simple detail level and a more detailed level. In this way it will be possible to limit the analysis in the early stages where the designer is only considering major items of equipment and does not want information on smaller features. At a suitable point in the design this can be toggled to allow the application of the full range of analysis and minor items of equipment.

Equipment Set-up

Most naval architects are not experienced in overall ship design to the extent where it can be claimed that they are expected to ensure all possible topside equipments are included. This part of the program is envisaged as an 'aide memoir' to the designer.

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[109] This information may be automatically available from the SURFCON Master Building Block. The Master Building Block containing top level information within the Building Block system [Dicks 00].

[110] This deck area would have already been defined if the system were implemented alongside the SURFCON system. If used in a stand-alone mode then the information input on approximate length, beam, draught and depth would be used to create an approximate deck outline sized to the input parameters.

Within the project the type of ship has been chosen and also the level of required detail. Working with this information a series of check boxes will allow the choice of equipment types to be selected. A default set will be applied for each ship type, a more extensive set applying to the detailed level. The designer will be able to call up this list and alter the requirements as necessary. The mode of operation is envisaged to be through check boxes, allowing the inclusion or omission of equipment types. Examples of the equipment types appropriate to a naval vessel are:-

- Air search radar
- Target information radar
- Navigation radar
- Sonar
- Long range communications
- Medium range communications
- Short range communications
- Satellite communications
- Electronic Counter Measures (ECM) and Electronic Support Measures (ESM)
- Anti-Air Warfare (AAW) weapons (including aircraft)
- Anti-Submarine Warfare (ASW) weapons (including aircraft)
- Anti-Surface Warfare (ASuW) weapons (including aircraft)
- Self defence weapons (including aircraft)
- Replenishment at Sea (RAS) requirements
- Lifesaving equipment
- Boats

This list illustrates the breakdown of the equipment items into specific types that can then be chosen as either required or not for the design in question. This information can then be used by the analysis programs and discrepancies flagged up to bring them to the attention of the designer. This will serve as an overall control of the equipment that it is planned to fit. It will enable the designer to consider at the outset the equipment fit required and not to have to cope with remembering what to fit whilst in the design process where it is easy to overlook initial requirements or individual equipment items.

Workbook

In order to document the design process a workbook facility will be incorporated into the system. This is an automated method of recording the design as it progresses, major program events are automatically logged into the workbook and the designer can interactively enter comments. Through correct use of this workbook facility a design audit trail can be established and necessary design reports readily produced [Andrews et al. 96].

8.2.4. Equipment Menu

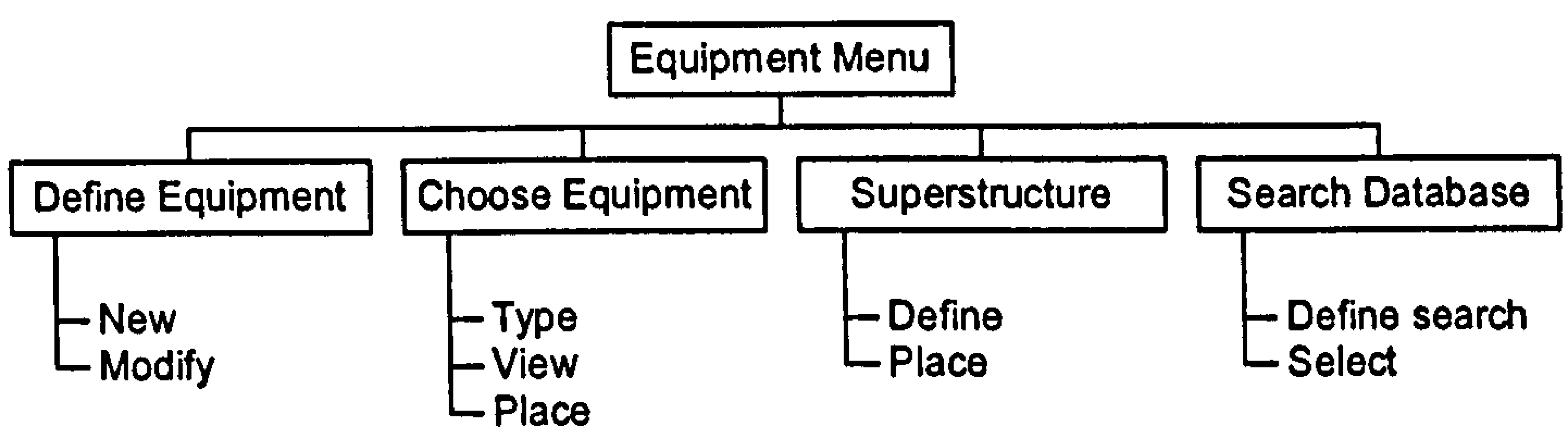

Figure 8.6 : Equipment Menu

One major role of a topside design tool is to capture information on equipment and make it available to the designer and the system. As designs are carried out, the database of equipment will grow and this should be readily available to the designer to draw from. The definition of new equipment items is only required where a similar equipment item does not already exist in the system.

Define Equipment

It must be possible to define new equipment items and for them to be added into the system database. Two methods are appropriate for this, firstly the modification of an existing equipment item, secondly a totally new definition. Modification provides an easier route for the naval architect as a full new definition will require some detailed information on the system that may require expert input.

Whichever method is used the initial choice of the type of system will then, due to its link with the database, provide prompts for all information required in order to provide a full definition for use by the system. This information will change depending upon the type of equipment, for example, radars requiring information on operating characteristics in addition to the geometric and weight details. Some of the simpler items of equipment, such as boats might require far less information and so the user will only be required to enter that which is appropriate in the particular case. The database record will be linked to a geometric 3D solid modelled definition of the equipment item created using the graphical system.

Choose Equipment

Through this menu the designer will have a list of types of equipment presented. This list will correspond to the checklist items from the equipment set-up menu. From these categories the individual items can then be chosen, along with their related properties, and placed into the design space. The database will not only contain specific equipment items but also details on other areas of topside arrangement such as exhausts and masts. This is basically an access point to the design database enabling the choice of systems and their placement within the design space. The manipulation is than carried out within the top level graphical environment.

Superstructure

In order to define the topside arrangement the designer must be able to place and modify blocks of superstructure. The designer must be able to define the type of block required, i.e. length, breadth and height as well as the angle of slope on the faces. This block can then be placed into the design environment in a similar fashion to the equipment items and positioned using the graphical interface. Superstructure elements are different from equipment items as their geometric dimensions are not fixed. It must be possible to choose, from within the system, a type of superstructure block to place but resize the block to fit the given design.

Search Database

A search facility is provided to allow the designer to search the database for equipment items if unsure of what is available in specific areas. This should be an open search allowing access to all fields, be they top level such a the name of an item of equipment, or very specific such as operating frequency. This will enable the designer to search for equipment that may meet the need.

8.2.5. Analysis Menu

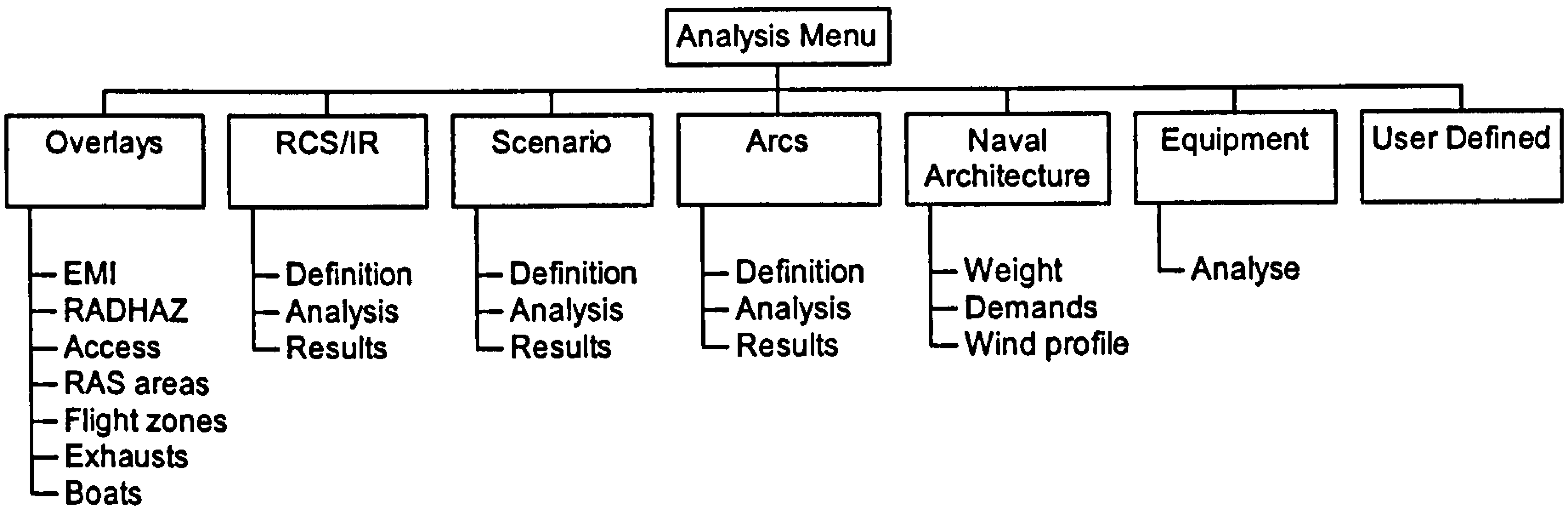

Figure 8.7 : Analysis Menu

The analysis menu, along with the graphical interface, forms the major part of the tool. It is through this menu that the designer is able to carry out the extra analysis that is possible with such a system rather than purely the geometrical constraints illustrated by a 3D CAD system.

Overlays

Through this submenu the designer has access to a series of overlays that can be seen within the graphical environment. It is possible to choose which of these overlays to turn on and off so as not to confuse the overall picture.

The overlay facility will enable the visualisation of information other than geometric about the particular equipment items. This information could, for example, be exclusion envelopes, safety areas or exhaust plumes. With this system it is possible to highlight interactions that are not due to the geometry of the equipment but rely upon the characteristics of the equipment. In this way the designer will be able to visually identify the interaction zones between equipment items that result from the underlying characteristics of the equipment. For those equipment items where no interactions exist the use of the overlay facility will aid visualisation by highlighting the particular equipment and ensuring that the designer can see that placement is not constrained.

Analysis Programs

In addition to the overlays that interact with the graphical environment there are a series of analysis programs that will use the geometry definition but the results will be presented separately from the main 3D design space. Programs envisaged are RCS, IR, scenario modelling and arcs of fire analysis. Further programs could be included when they become available, such as airflow in way of the flightdeck. The choice of this type of analysis will result in a prompt screen to the designer asking for information required for the particular analysis. The program will then run and present the results, this will be in the form of either graphical or numerical solutions. These can then be printed or saved for later printing via the output menu.

Naval Architecture

It is important to realise that the topside design cannot be carried out in isolation from the rest of the ship. As discussed the proposed system will integrate with the SURFCON system to provide a complete design tool [Dicks 98], [Dicks 00], [Andrews 01], [Paramarine 02], [Andrews & Pawling 03], [GRC 03]. This interface will allow full analysis of the ship for basic naval architecture considerations such as stability and structure. However within the topside design tool it is important to provide the naval architect with information relevant to the rest of the design. The most obvious of these is the weight distribution of the topside arrangement. Heavy equipment placed high in the ship will have a large impact upon the stability of the vessel. It is important that this information is available so that informed decisions can be made on alternative equipment positions without necessarily having to revert to the SURFCON system.

Equipment

The equipment analysis section allows a comparison to be carried out on the equipment items fitted and those defined in the project set-up. Discrepancies can be highlighted allowing the designer to place additional required equipment or to re-assess the initial definition. This simple checklist process ensure control of the design is maintained as it develops.

User Defined

The final part of the analysis menu is a user defined section. This allows the user to apply any specific user defined analysis by accessing information held wihin the topside tool. In this way all the information held within the design tool can be accessed and used as required.

8.2.6. Output Menu

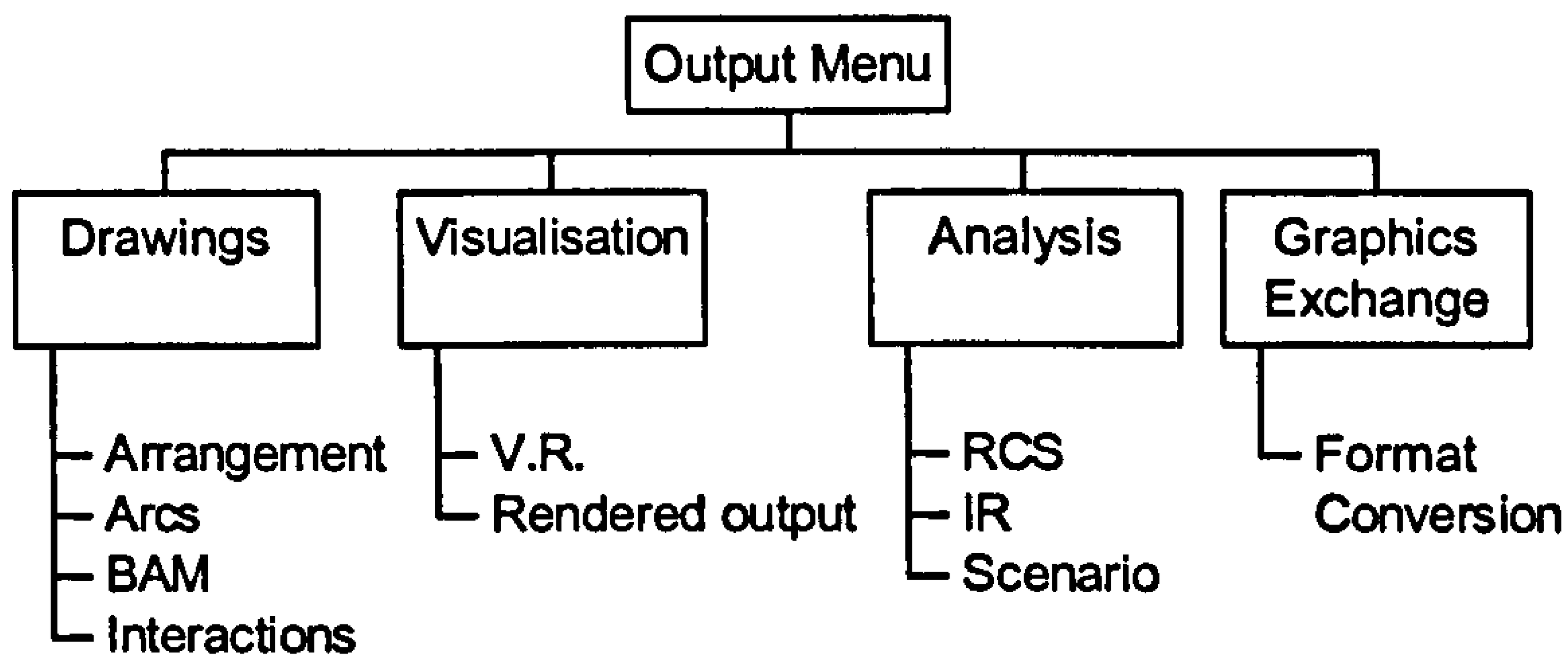

Figure 8.8 : Output Menu

It should be possible to output in hard copy from the system all information that would be required in a report on the concept development. This can be split into three major areas of output.

Drawings

Although the computer system and graphical interface is in 3D the final, hard copy, output must be 2D drawings and these must correspond to the drawings currently in use. Several forms of output can be envisaged, layout or arrangement drawings indicating the positions of equipment on the decks in both plan and profile views provide the hard copy definition of the fitted equipment items. In addition the output of Arcs of Fire and Blockage Assessment Models (BAM) show the physical limitations placed upon the equipment by the geometry. The final type of drawing will be obtained from the different overlays that are applied in the analysis stage of the design, these can either have one single overlay or show the contribution of many.

Visualisation

The use of the 3D CAD system will allow for presentation quality visualisations to be produced. The most simple of these being the production of a 3D view, this should allow for the addition of the sea surface and a choice of views. An additional facility that could be used for design presentation is the use of a virtual reality walkthrough or flyround. With such a facility the designer could be allowed to define a path through the geometry and obtain an animated output [Autodesk 90], [Paramarine 02].

Analysis

The analysis output will produce hard copy of the separate analysis programs that have been run, without rerunning the particular analysis. This output will consist not only of graphical data but also numerical information and will cover more detailed areas of analysis such as RCS, IR and scenario modelling.

Graphics Exchange

This facility will allow the import and export of model geometry into the graphical environment. This will allow the data to be used on systems using different CAD packages, the exchange could be through a standard file formats such as the International Graphics Exchange Specification (IGES) [IGES 96] or the Standard for the Exchange of Product Model Data (STEP) [ISO10303 01].

8.3. Proposed Design Process

The starting point for any design is to establish a base on which to build up the ship topside description. For frigate sized vessels it is often the topside arrangement that governs the overall topside length [Brown 87] and so in order to ensure that the design is not constrained, no deck outline is used at the start of the design. The initial starting point is to place, within the 3D design space, the major equipment items that are intended to be placed on the ship. These can be chosen from the database of existing equipment items or entered by the designer, the database providing the prompts for the information that is required. If the designer is unsure of which particular equipment is required, the database can be searched for equipment best meeting the required specification. It is important to realise that it is not only weapon systems that must be placed in this first phase but also some structure as all ships require, for example, a bridge, and its placement has a major impact on the subsequent layout. The choice of these top level items is aided by the two-tier database. One level contains those equipment items considered of major importance, with a second layer only being visible when the designer wishes to consider a more detailed level. A further benefit of this centralised database is that standardised reports can be produced about the design at any time or design reports created reporting the basis of design decisions. These can be simple reports, for example listing the equipment placed in the design, or more complex ones, for example a list of those types of equipment items not yet placed, ensuring that all the necessary items have been placed, be it at the initial or detailed level of design.

The items that are placed topside contain not only the geometric data about the equipment but also the relevant geometric constraints. These can be such things as separation required from other equipment for electromagnetic reasons or blast/efflux zones associated with guns and missiles. For the topside design system these additional geometric constraints will be switched on or off from screen display by the designer so that only those that are being considered are displayed. It is then possible to start laying out the equipment within the 3D design space, using the additional geometry constraints to aid placement decisions.

Once the major items have been placed within the design space it is possible to define a rough deck outline, the placement of items having defined the minimum length and beam required. Additional structural elements[111] can then be placed it order to provide support to the items and the equipment can then be further constrained to this structure.

Although very vital to the designer, placing equipment and structure does not provide the total topside design solution. It is important to be able to analyse the design as it

[111] As part of the initial design work the main superstructure will have been sized and positioned. Once equipment items are also located in suitable positions further structure may be necessary to support them. This may require the addition of extra platforms and masts, or necessitate an increase in overall superstructure size.

evolves. The topside environment is very complex and the aim of the methodology is to present all the requisite information to the designer, who may not be a specialist in all areas, in a clear format when required. It is important that the latest picture is reflected in any analysis routines used and that feedback is as instantaneous as reasonable practicable. There are many underlying routines that are available to enhance the designer's view of the overall total topside as further equipment is placed, or existing equipment moved. Some of these routines are still geometry related, but others provide additional information about the topside environment as a whole. The open architecture of the system allows for many different analysis programs and routines to be integrated. By using one single database to contain all the information and linking this to the geometric definition of each item, it is possible to provide data for many different applications, all that is required is for the database to hold the necessary information.

The designer also needs to place the antennae. These greatly influence the electromagnetic environment of the topside and currently it is difficult to maintain clarity as to all the interactions. The methodology proposed allows a designer inexperienced in electromagnetic interference to avoid many such EMC problems. The knowledge base aids in the choice and location of items as does the additional geometric data held in the model. Rules do exist on the antenna location and they are often expressed as simple guidelines, such as separation distances between receivers and antennae. This data is not complex but can be difficult to use as a design evolves. By embedding these rules into the equipment geometry and the knowledge base it is possible to provide the designer with all this information in a form that can be easily visualised. The display can then be configured to show EMI interactions only, reducing the information overload from other equipment items and interactions. Thus the designer does not have to be an expert in the field, nor does he have to continually refer to standards in order to reach the best design compromise.

The final output will consist of many different graphical and numerical items. It is simple to produce drawings of the proposed layout, but these can be backed up by all of the other information created whilst building up the design. These can range from simple blockage assessment diagrams for all of the equipment through to output from scenario assessment, RCS prediction, and flyrounds of the completed topside arrangement. All of this information is generated from within the same system and from one single design model. The integrity of the data is ensured and the confidence in the overall design arrangement is greater than if manually produced.

8.4. Simulation of the System

In order for the methodology to be proven it has been necessary to simulate the proposed system using computer tools and development programs available commercially. The approach adopted has been to take existing tools that can perform the individual requirements and use these, along with some manual transfer of data when required, to produce a breadboard system. This system has been used to develop the methodology allowing the research to focus on the interaction of data and requirements for information.

The breadboard system has used the following components:-

- AutoCAD V13/V14[112]
- Autodesk Mechanical Desktop V1.2/V2.0[112]
- Microsoft Office 97/2000[113]
- Matlab[114]
- Autodesk 3D Studio[112]
- Paramarine V2/V3[115]
- Bespoke computer programs

The use of these programs has allowed all of the major functions to be investigated. AutoCAD and Mechanical Desktop provide a 3D parametric solid modelling environment, allowing part and assembly modelling. This simulates the graphical user interface and allows for existing parts to be placed into the design space,

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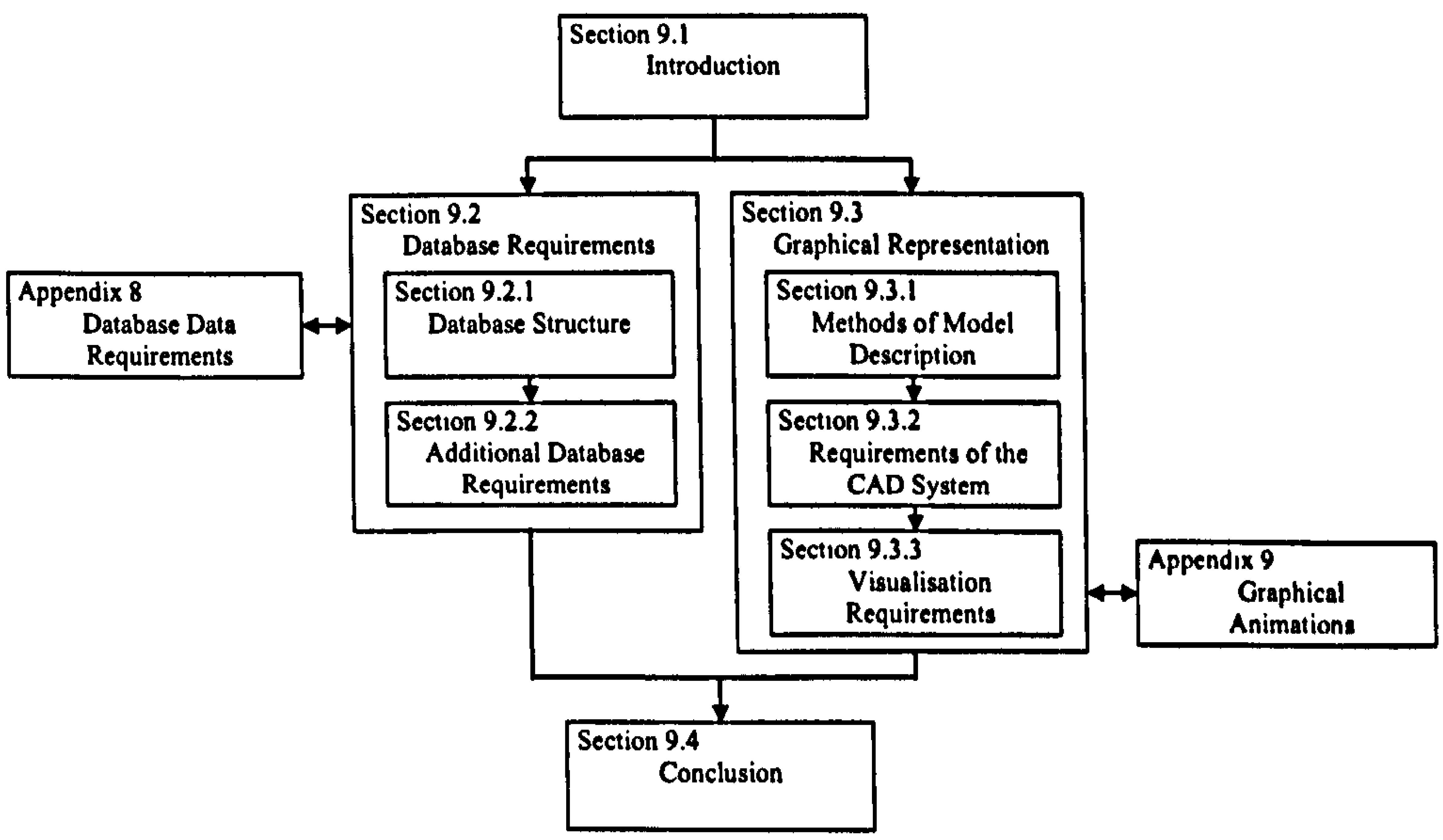
[112] Commercially available CAD software from Autodesk allowing 3D drawing, solid assembly modelling and visualisation [Autodesk 90], [Autodesk 95], [Autodesk 97a], [Autodesk 97b].
[113] Commercially available office applications, Word, Excel, Access and PowerPoint providing a word processing, spreadsheet, database and presentation capability (www.microsoft.com).
[114] Commercially available mathematical software (www.mathworks.com).
[115] Commercially available ship design software [Paramarine 02].

parametrically[116] sized if necessary, and constrained. It has not proved possible to fully simulate all constraints required by the proposed system as Mechanical Desktop only contains a limited number of constraints due to its design as a mechanical assembly modeller. It is difficult to invoke constraints of the form, 'not closer than', although this form of constraint is desirable when placing parts requiring separation distances. The control of these constraints has been achieved by manual means, utilising the drawing aids[117]. Paramarine has been used in the later stages of the research as functionality had increased to the point where the required solid modelling capabilities were available.

Other required functions, for the breadboard system, are carried out by parts of the Microsoft Office suite, Matlab, 3D Studio (an Autodesk visualisation product) or bespoke computer programs developed for particular aspects under investigation. This allows simple calculation, analysis, presentation and visualisation to be carried out. For the breadboard system these programs have been kept simple and the input carried out manually, rather than being read from the database. The output is straight forward, providing the data, but not necessarily in a final format. The use of 3D Studio allows for virtual flyrounds, whilst highlighting the importance of common data exchange formats. Whilst working on the design it is possible to view rendered images and rotate them in real time.

[116] The dimensions of the graphical representation are controlled by a number of numerical variables that can be altered or linked to other variables to resize the 3D geometry as required.
[117] The proposed topside tool will require a number of constraint placement aids that are not generally available. The designer will wish to constrain items to be on the deck, next to the bulkhead, a known distance from another item etc.

9. DATA STORAGE



9.1. Introduction

The system outlined in Chapter 8 requires various different forms of data storage. It is important that all of these requirements can be met as it is the storage and accessing of data that is key to implementing the proposed topside design tool through the methodologies outlined. Two areas are relevant, storage of data about systems as a series of database records (Section 9.2) and storage of graphical information in a CAD system (Section 9.3). The requirements for these two forms of data storage are outlined and examples presented of the data used in the breadboard system developed. The basis of the system is that the user should interact with the graphical representation, using the information in the database for interrogation and reporting.

9.2. Database Requirements

It is through the database records that all non-graphical information about items is recorded. This database also maintains control over those items placed in the design and provides a single source of data for feedback to the user. One of the benefits of this system is that as more designs are carried out so the database will grow. The database structure is presented and then the requirements of the database outlined.

Throughout the course of this study, for demonstration purposes, Microsoft Access has been used as the basis for any database work. A full working database has not been developed, as part of the breadboard system, as this would require specialist programming in order to meet all of the requirements outlined later in this subsection. Unlike the graphical work, a combination of simple database records combined with paper records has provided adequate data storage to demonstrate the methodology. The major advantage of producing a single database is automatic data transfer which in the research presented here has been carried out by hand. In doing so a full record of the data requirements has been kept and this is shown in Section 9.2.1. This can be used as the basis for constructing a full database.

9.2.1. Database Structure

For any item placed into the 3D design space a corresponding database record is required. This is necessary not only for all equipment items but also for structural items such as the hull and superstructure. As a result the database structure must be able to store many different types of item which the designer can then access. This requirement means many different types of data have to be accessed through a single interface. In effect the database has to be comprised of many different sub-databases, each specifically designed for a particular equipment type. This is necessary as the fields within each database depend upon the type of information it is necessary to record for a particular item.

Two major types of record are required, the first relates to specific equipment items and as such, once created remains fixed, unless details of the piece of equipment change. This type of record will form the majority of the database. The second relates to items that are used to create the structure of the ship, superstructure blocks, bridge, bridge wings, funnels etc. For these items the basic description is required but the dimensions are not fixed, for example the user must be able to choose a particular type of funnel, but then reshape the item to fit the design (discussed in Section 8.2.4). This will result in the final structure element being specific to a particular design.

Further control over the design can be maintained through the use of a two-tier database structure. This allows for the database, once the choice has been made, to be restricted to major[118] equipment items. The user is not swamped by the large amount of data within the complete database at the outset of a design. When a choice is made to restrict the database, only those items that have been recorded as part of the restricted database are available to the user. This two-tier database structure can be achieved through choices made when inputting equipment data. For each record a choice is made, by the designer, and database records shown according to this choice. This restricts the information and makes choices about major equipment

[118] The two tier database system will be set up by the designer in the initiation stages of the design. The use of checklist will allow a list of required equipment to be compiled for the ship type under consideration. This list will also allow the designer to indicate which equipment items are considered major items. These will be included in a restricted database containing only these major items.

items easier, without the added complication of large amounts of data about minor items. Once the design has progressed to a stage where most major decisions have be made the user can chose to enter a detailed design mode. The full database becomes accessible and all further equipment items can be seen within the database. Figure 9.1 shows a top level breakdown of the proposed structure.

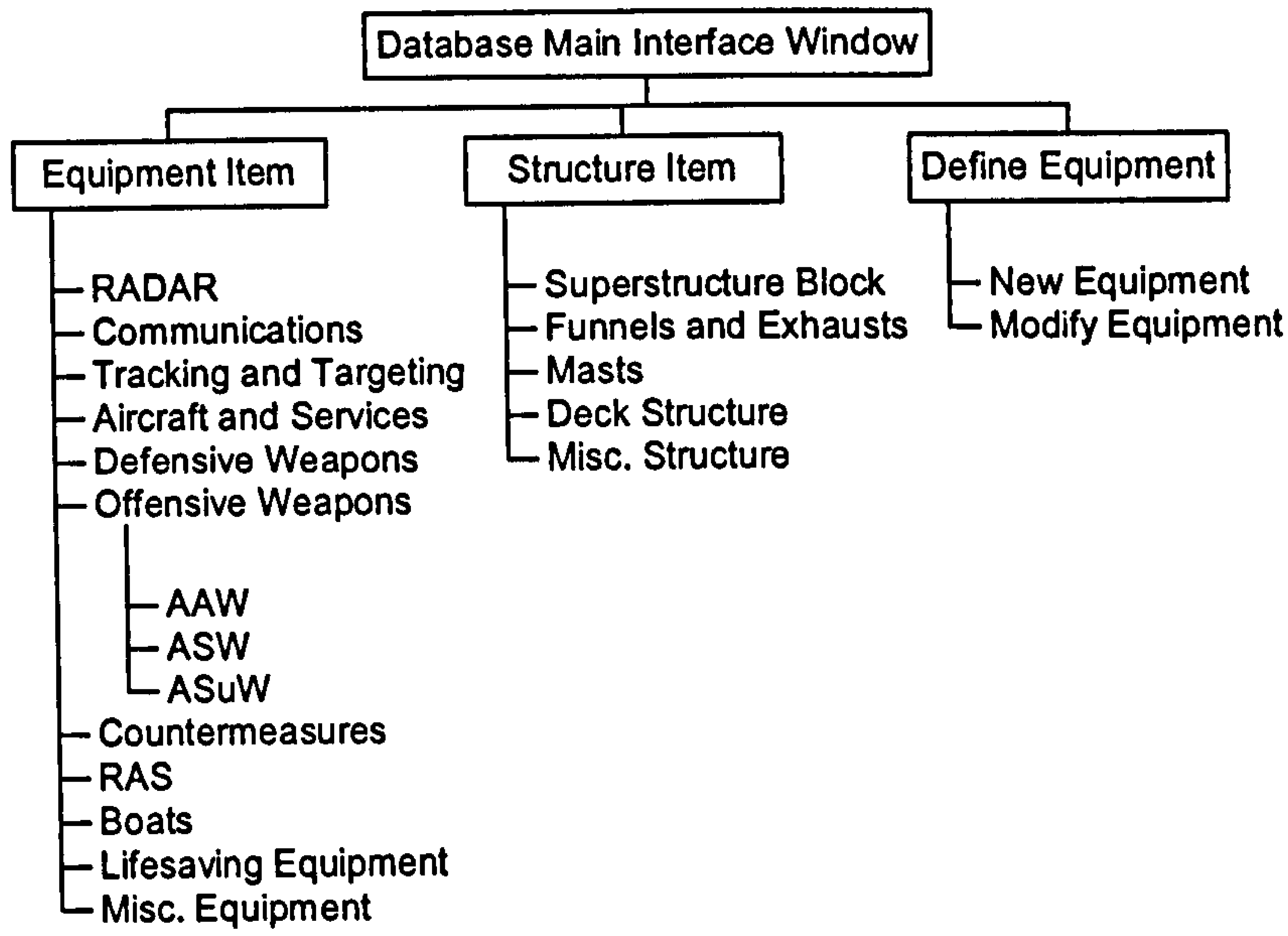


Figure 9.1 : Proposed Database Top Level Breakdown

The top level has been broken down into three major sections, two of these relate directly to the storage of data, the third is a method of defining further equipment items. As has been discussed there are two types of data to be stored, the first is fixed and relates directly to an equipment item, the second relates to ship structure and is more flexible in that dimensions when placed into the design are allowed to alter. For both of these types of data it must be possible to add to the database. This can be through modification of an existing item, applicable where an updated piece of equipment is used, or the addition of a totally new equipment item[119].

Appendix 8 describes in more detail the data requirements for the equipment items and the superstructure items.

[119] By necessity, the database will have to hold information about the equipment items. In some cases this information may be sensitive and appropriate security controls would need to be placed on the distribution of the database and also on any designs created using it.

The example database record shown in Figure 9.2 has been constructed to show a possible method of presentation to the user. The user is not provided with all the data about the equipment item on a single sheet, layers are used to avoid the user being swamped by too much data, such as:-

- Details (basic equipment detail and descriptions)
- Space and Weight Data
- Advanced Modelling Data
- Scenario Data

Image removed due to third party copyright

Figure 9.2 : Example Layout of Database Record [Andrews & Bayliss 98]

The important description data can be shown on a single page and is essentially a picture of the item and an associated description, this includes a name, type of equipment and a summary of the equipment usage. Also presented are the requirements for other items, in this case a flight deck and hanger. These are additional items held within the database and the user is prompted to add these items. This example shows the associated graphical representation of the item as the picture. Final implementation may allow for two pictures, one being the graphical representation but in addition a full colour photograph of the equipment item.

Space and weight data can be recorded as this information is important when considering the interface with the SURFCON system [Dicks 98], [Dicks 00], [GRC 03]. Although the proposed topside design system does not include the effect of weight and space on stability this information would be required by any companion system modelling the ship hull and stability[120].

The advanced modelling data denotes further information about the system consisting of a description of any further graphical information that is held as part of the graphical model. This would be information held in other layers relating to aspects such as access requirements and EMI exclusion zones (Section 9.3.2). Further to this information would be any data required to enable the application of the further methodologies detailed in this thesis. Scenario modelling requires additional data to be stored specifically to allow the application of a scenario modelling program. This requirement is detailed in Section 7.3 and Appendix 6.

9.2.2. Additional Database Requirements

The database must be capable of performing several tasks in addition to the simple storage of data. It is through this capability that the full benefits of the proposed system would be accessed and the implementation of the methodologies outlined in Chapter 4 made possible. The use of a database with associated graphical representations allows considerable design data to be recorded and reported upon. These can be summarised by the following subsections detailing design control requirements, checklists, reporting and external links.

a) Design Control

One of the major problems facing a designer when considering a new design is the control of information. The ship topside is highly complex and composed of many different equipment types. It is easy to become too concerned with a single element or aspect of the design and to ignore other elements. The use of an integrated system with a single repository for data allows for the full progression of the design to be recorded and gives the designer the tool to allow many analyses to be carried out concurrently.

[120] Information about overall ship weight and space (including all items within the hull and on the ship topside) would be included as part of the Master Building Block in the SURFCON system [Dicks 00].

The designer chooses equipment items from the full database and in doing so builds up a subset of features that form the design under investigation. This subset of features provides a full record of desirable equipment and features placed in the design and can be used by the designer to provide a design record. This can be achieved through the generation of checklists and reports.

b) Checklists

As the design progresses a series of checklists can be used to maintain design control and ensure that the design aims are met. These checklists can be generated by the designer at the outset of the design or compiled from information held within the system. For example a designer may wish to design an ASW ship. At the outset design aims can be set and recorded as a checklist. This can be information relating to the types of weapon required for an ASW role or specific equipment. In addition to this checklist data, automatic generation of additional checklists provides the designer with further prompts. An example of such an automatically generated checklist item can be seen when considering lifesaving equipment (discussed in detail in Section 10.3.2). Once the approximate number of personnel for the given ship type is decided the system can automatically generate the requirement for lifesaving equipment. This is a simple rule based decision, but once captured as part of a checklist provides a prompt to the designer. It is important that the system administration ensures that the latest versions of design guidance are included in the system. The user should not have to check the applicability of design standard as this negates some of the benefit from computerising the rules.

These checklists need to be available to the user whenever required and must reflect the latest state of the design.

c) Reporting

Documentation of a design as it evolves is an important part of the design process and this can be aided through the use of standard reports generated by the system. These reports must be generated automatically and reflect the state of the design at a particular instant in time. A simple report would be one detailing all of the items placed within the design and their locations. This generation of these reports must be straight forward and use a standard format allowing for design documentation to be carried out in a simple and efficient manner. By providing this facility, improved recording of design progress is possible as the recording task itself is minimised. The output is likely to be more comprehensive than if the task were carried out by the designer without the aid of this feature, given designers often sacrifice comprehensive reporting in order to expedite the design progress.

Further specific reports could be used to document particular aspects of the design, for example the user could require a detailed report on the communications systems. This report would list the items within the design space, their position, but also further information relating to the operating bands. This information can be associated with the checklist information for a communication system and discrepancies with regard to meeting the requirement highlighted.

d) External Links

It is important that the database is not an isolated entity but can transfer data to other programs for further manipulation. The nature of a database means that for each item there is an individual record. For some of the proposed tools it is necessary to manipulate data from a variety of equipment items and to present results from this data manipulation. In order for this to be achieved the data held as part of the database must be accessible to further analysis of this type. One example is the use of the database information in the generation of Frequency Spectrum Utilisation Charts and EMI Source Victim Matrices as discussed in Section 5. Thus it is necessary to access the database and draw from it information as to which elements have been placed, and details of their operation. This data can then be analysed and results presented.

9.3. Graphical Representation

The graphical representation forms the second major area of data storage, and the investigations carried out are detailed below. The different methods of representation available are described and illustrated (Section 9.3.1). This is followed by the requirements of the CAD system for implementation within the proposed system (Section 9.3.2). A final section details further requirements in order to allow full design visualisation to be carried out (Section 9.3.3).

All interactions with the system and arrangement of equipment is to be carried out through a graphical interface. This requires all items to be represented in a graphical format. Throughout the course of this research the breadboard system described in Section 8.4 has been used. It is not considered appropriate for this thesis to recommend any particular software elements but to document the functionality required from any commercially available CAD system used to implement the final tool. The CAD elements used for investigation purposes were made up from a combination of Autodesk products. AutoCAD R13 [Autodesk 95] and R14[121] [Autodesk 97a] were used as the basis for CAD work. Mechanical Desktop[121] [Autodesk 97b] was used as a solid modeller add-on to AutoCAD with mechanical assembly capability, 3D-Studio[121] [Autodesk 90] was used for further visualisation requirements. Later investigations made use of the Paramarine software [Paramarine 02]. The required capabilities may well be present in readily available software but depending upon the software of choice, enhancements may have to be made to ensure all the requirements considered necessary for the system can be met.

9.3.1. Methods of Model Description

The requirement for a three dimensional representation of the equipment item results in three possible methods of modelling:-

- Wireframe modelling
- Surface Modelling
- Solid Modelling

a) Wireframe Modelling

This is the simplest form of CAD representation for a three dimensional shape. The geometry is described by a series of lines, placed into the three dimensional design space in such a way as to represent the overall geometry of the system. This is a simple way to create a three dimensional representation as the description is often

[121] All of the Autodesk products detailed are supplied as software with electronic on line documentation. For full description of program capabilities reference should be made to the software program or the Autodesk website (www.autodesk.com).

composed of only two dimensional curves. An example is shown in Figure 9.3 where a four tube missile system is represented by three orthogonal views. This geometry has been extracted from the GODDESS database of equipment [GODDESS 91] where many equipment items are represented in this way. The wireframe geometry has been imported into AutoCAD to produce the figure shown here. The overall physical shape is not immediately clear from this view.

Image removed due to third party copyright

Figure 9.3 : Wireframe Representation of Missile System [GODDESS 91]

It is not necessary to use three orthogonal views, other wireframe representations can be constructed. In order to allow easy recognition from all angles these models can become complex and difficult to construct.

b) Surface Modelling

This is a more complex form of geometry representation where a surface definition is created that describes the shape of the external contours of the equipment item in question [Koelman 02]. The advantage of this definition is that it is a full representation of the geometry and can be shaded (rendered) to illustrate the item. It requires far more work to define than wireframe as surface definition is not simple and many surfaces need to be combined to create the illusion of a solid shape. This method may be most applicable where the hull geometry may be taken from another CAD system where surfaces are used to represent the hull.

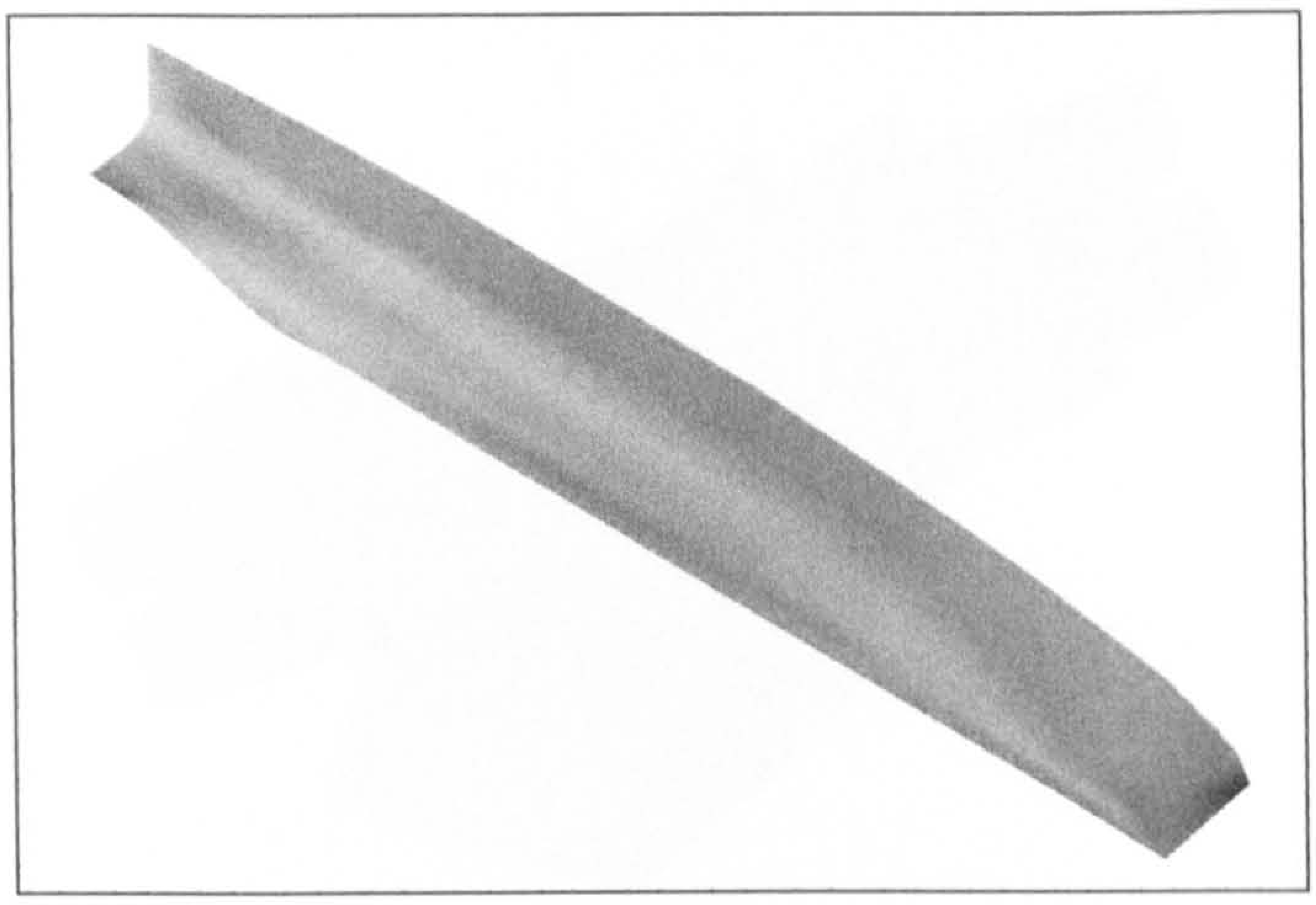


Figure 9.4 : Surface Representation of Port Hull of a Naval Vessel

Figure 9.4 has been created in AutoCAD using a set of body plan curves and lofting a surface to fit these curves[122].

c) Solid Modelling

With solid modelling the three dimensional shape is represented within the computer as a solid. This solid shape can be combined with other shapes to create a representation of the equipment item. This method or representation is becoming far more popular in the manufacturing world due to the fact that material properties can be captured as well as centres of mass, densities and other parameters. This is not important for the work discussed in this thesis, what is important is that a full solid three dimensional representation can be created reasonably easily for any item of equipment. The same four tube missile system that was shown as a wireframe representation (Figure 9.3) is shown in Figure 9.5 as a full solid model. This model has been created using the Mechanical Desktop add-on to AutoCAD to allow full parametric[123] 3D solid modelling and is based on the lines from the wireframe model. The representation is far more easily understood.

[122] A generic set of body plan curves was created using the UCL developed computer code HULLFORM [Wray 82].

[123] The dimensions of the graphical representation are controlled by a number of numerical variables that can be altered or linked to other variables to resize the 3D geometry as required.

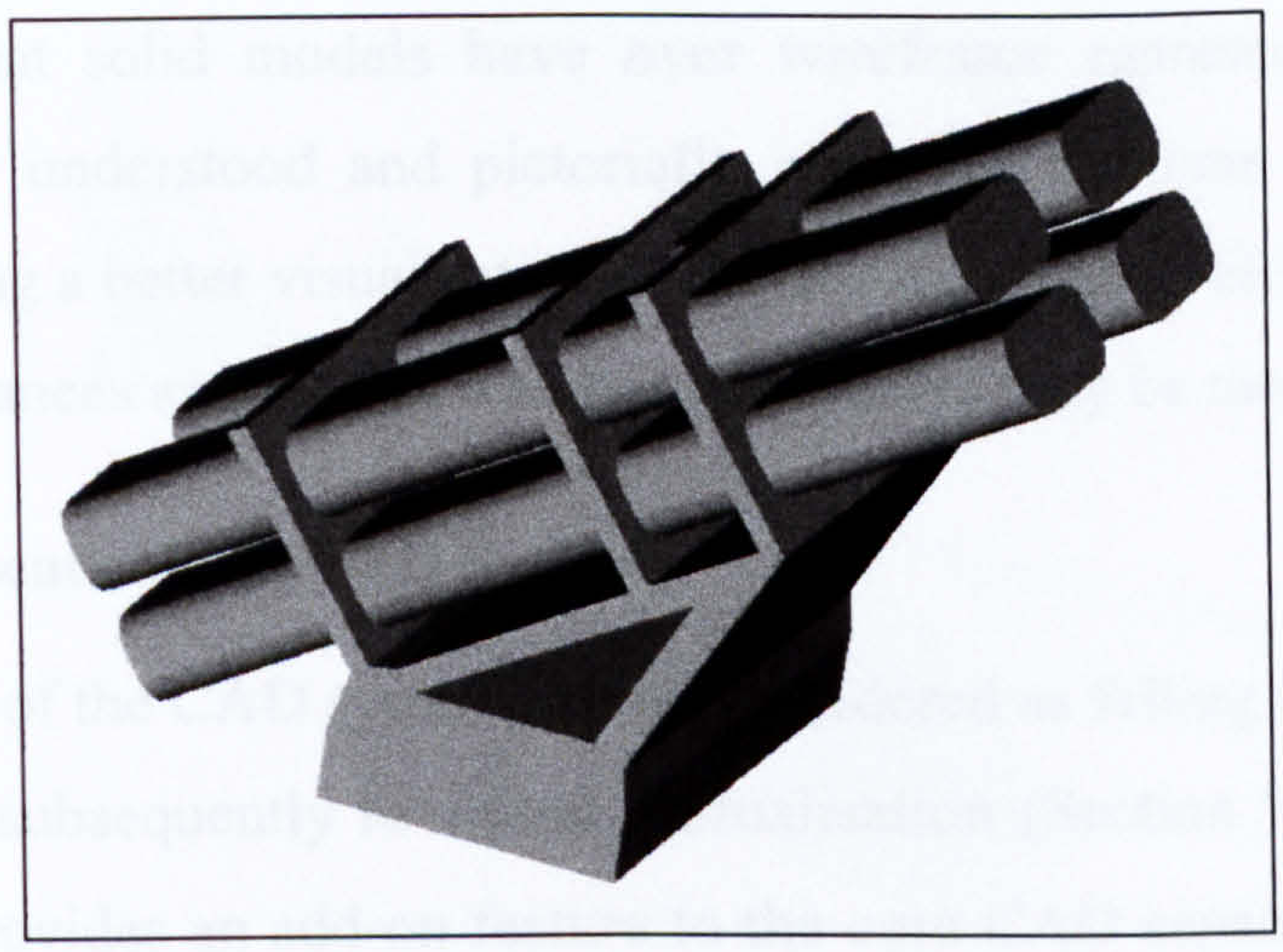


Figure 9.5 : Solid Model Representation of Missile System

All three types of models are suitable for use in the proposed tool as they all contain the three-dimensional information likely to be required. It is proposed that solid models are used, where possible, as they are more easily constructed than surface models and represent the system far more clearly than wireframe models. It is possible to use a combination of these methods where models already exist in a particular format.

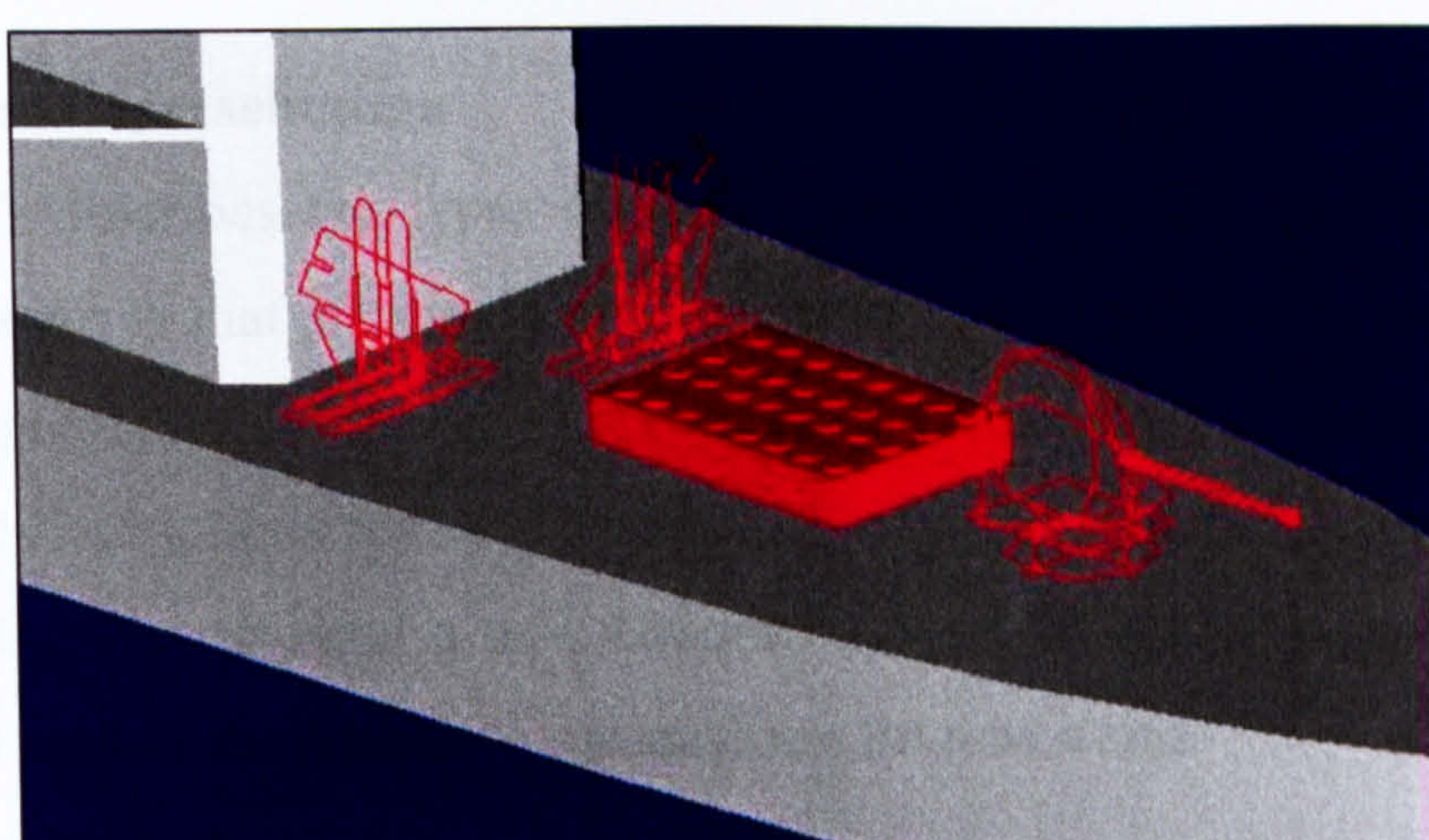


Figure 9.6 : Combination of Wireframe and Solid Models

In Figure 9.6 the wireframe representation of the missile system can be seen in combination with a wireframe gun system but solid representations of a vertical launch missile silo and ship structure. This figure has been generated from the Mechanical Desktop software. Each item has been drawn or imported from an external source. The full model has then been assembled by importing the individual elements into a single design space and arranging correctly. This figure demonstrates the advantages that solid models have over wireframe representation. The solid models are easily understood and pictorially represent the item they describe far more fully allowing a better visualisation of the combination of elements, however in dealing with clearances and hidden features wireframes may be more appropriate.

9.3.2. Requirements of the CAD System

The requirements of the CAD system can be considered as falling into the six aspects listed below and subsequently reviewed. Visualisation (Section 9.3.3) is dealt with separately as it provides an add-on feature to the core CAD capability which is seen as a major element of the proposed system.

a) Graphical Representation
b) Graphical Manipulation
c) Graphical Layers
d) Placement Constraints
e) Drawing Preparation
f) Import and Export Features

a) Graphical Representation

Section 9.3.1 describes the types of model description. The requirement for the proposed system is that all should be useable in combination with others. A lot of computer representation already exists in various formats and users may want to import these descriptions into the system. This would require the least amount of work from the user to input a new equipment item. It is recommended that solid modelling is used as the primary representation for new items.

Each new item should consist of a single CAD model that describes the complete system to be placed. When being placed into the current design the user should only need to manipulate a single element. Therefore if the equipment item is such that it is composed of many separate individual elements, these need to be combined into a single model that is then used as the graphical representation for that particular equipment item. This is best described through the use of an example.

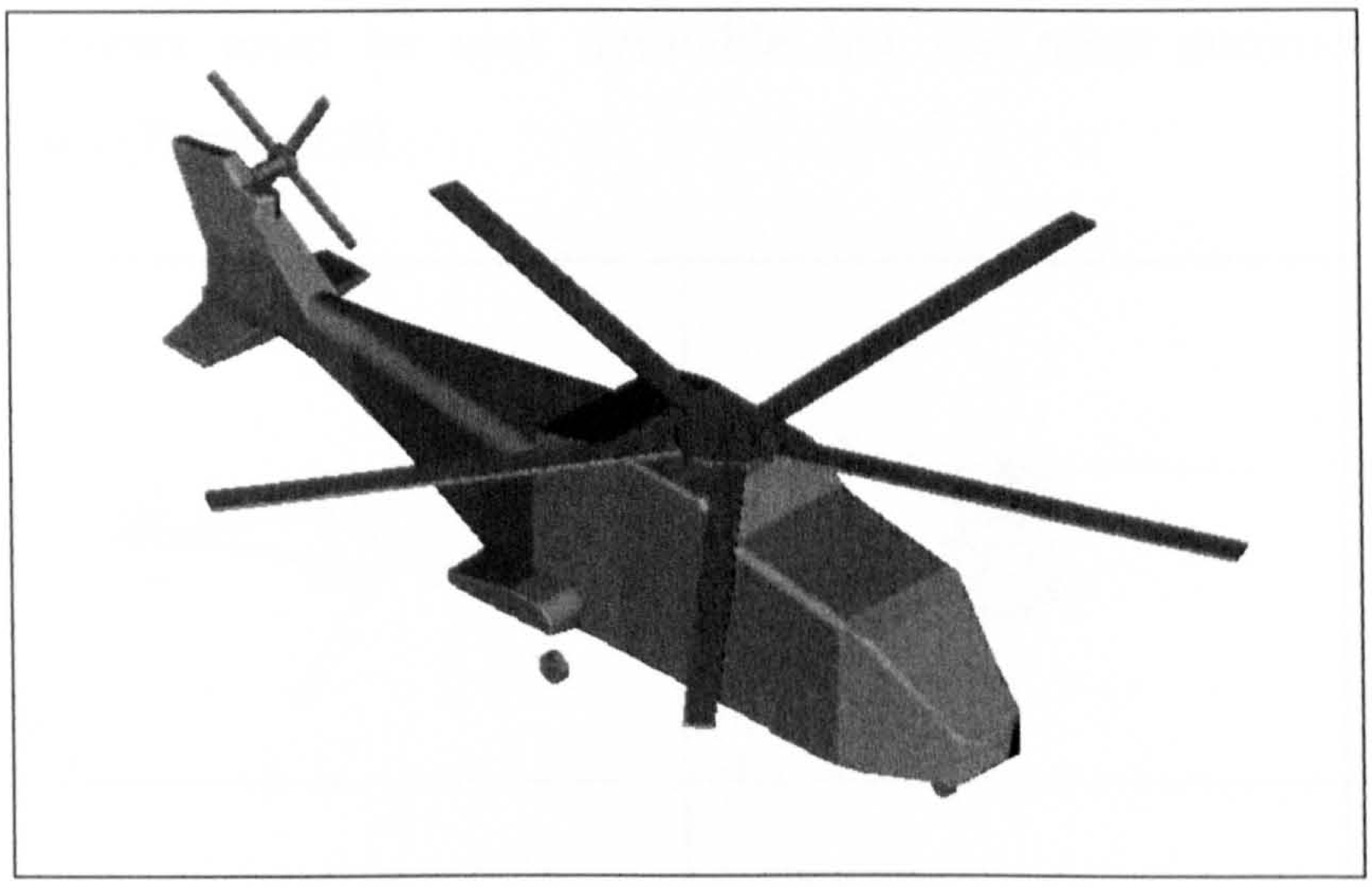


Figure 9.7 : Complete Helicopter CAD Model

In Figure 9.7 the helicopter representation is made up of many different individual items, the fuselage, tail rotor, tail plane, main rotor, wheel pods and wheels. This information is combined into a single CAD representation for the overall helicopter that is then used within the proposed topside design tool. This requirement demands more background work in the development of the model before it is imported into the topside tool but removes any possibility of the user being confused due to multiple part models. In the example presented each of the items was developed individually using Mechanical Desktop and then all were imported into a single design and combined, resulting in a single solid representation that is manipulated as one part.

For each item it must be possible to change the colour used to show the item. This is important during model development as it allows easy identification of element types.

b) Graphical Manipulation

The graphical window is the main user interface with the system. A menu system will be used to allow the choice of items from a database but once chosen and placed into the design space all further manipulation is carried out in the graphics window. As a result it is important that this window can be configured to allow the user to manipulate the item in the most efficient manner. Most CAD systems, when representing a three dimensional space allow the user to define the type of view they wish to see, this may be a single window, or a series of windows showing different views. These views must be user definable but the most commonly used are orthogonal views (Figure 9.8).

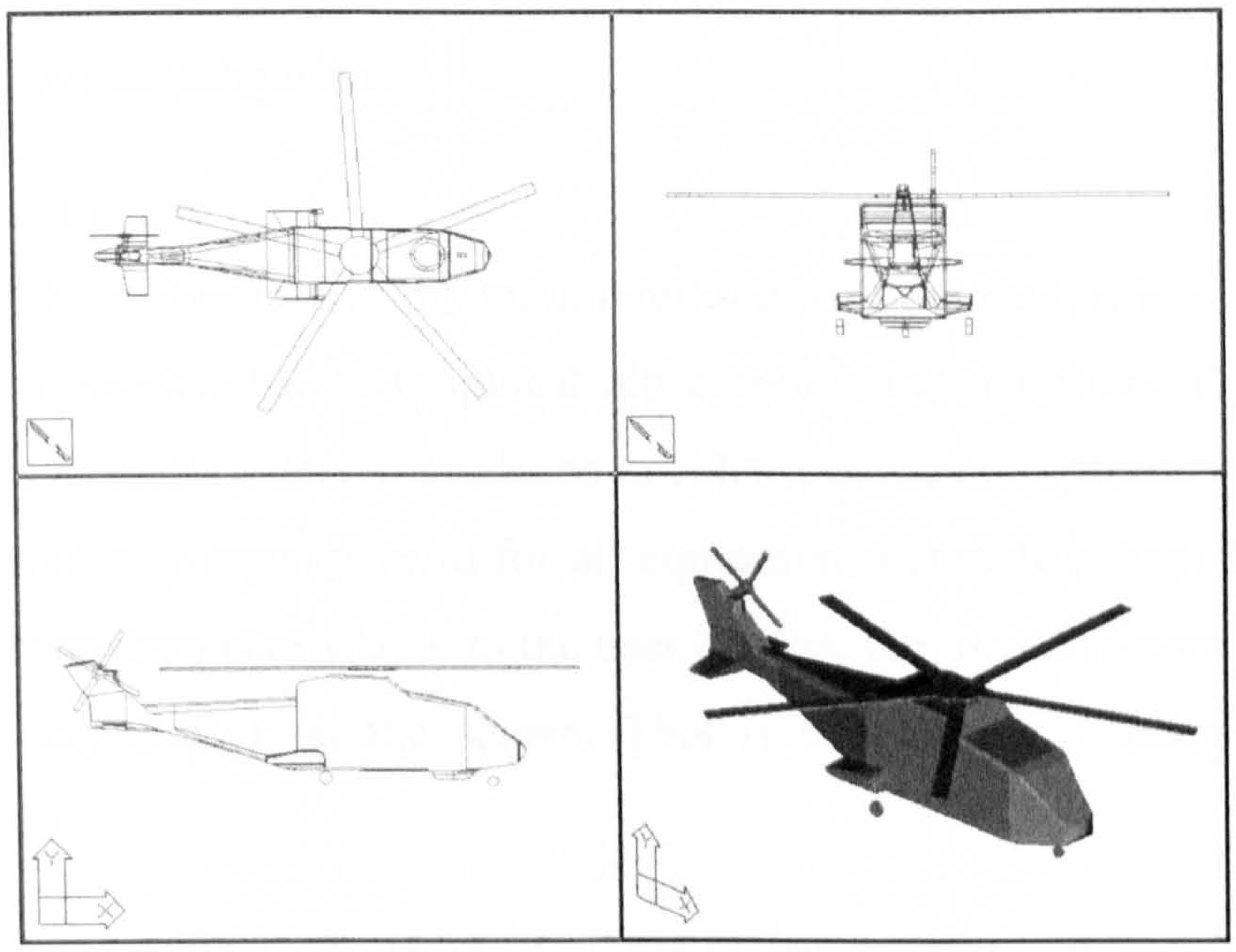


Figure 9.8 : CAD System Showing Orthogonal Views and 3D Isometric View

Here the screen from the Mechanical Desktop software [Autodesk 97b] is shown with the helicopter element previously described. The use of the orthogonal views aids placing elements since it depends which window is used as to which movement is constrained. In the example the lower left window is chosen[124] allowing movement in the x and y directions but not in z.

It is important that as the design evolves a complete picture can be seen. This is achieved through the use of a view allowing real time rotation of the design. Through movement of the mouse, the entire design can be rotated about a fixed point in any direction, this allows examination of the design from any angle.

As a design evolves the overall picture can become confused due to the number of elements placed within the design space. In order to allow items to be highlighted it must be possible to toggle their display on or off. Additionally it must be possible to represent items either as fully rendered or wireframe views. The rendered view is

[124] The chosen window has arrows indicating the direction of the axes. The broken pencil shown in the two top windows indicates that no manipulation can be carried out in these windows.

only available to those elements with either surface or solid model descriptions, but it must be possible to display these items in wireframe format if desired. This would then allow the user to retain their representation on the screen without obscuring other items under investigation.

c) Graphical Layers

Since the graphical interface is the main interface with the user, it is used to present information in addition to the graphical representation of the item. This additional information is a result of design guidance or rules and may be specific to a particular type of equipment or equally valid for all equipment items. It is important that this additional information is available to the user but that the user is in control of what is displayed at any instant on the screen. This is best achieved though the use of different layers.

A graphics layer is essentially an overlay that can be applied to the view displayed to the user. This overlay is toggleable and can be turned on and off by the user. The use of layers allows for further information to be stored graphically and linked to equipment items, but only displayed when requested.

An example of the use of this additional information is access. All equipment items will have an associated access requirement, this may be for maintenance, or for other tasks such as reloading. This information can be recorded graphically for each CAD model and developed as an additional layer. When considering the access requirements the user can toggle the access layer on, and then for all items with an access layer defined, the additional information can be displayed. These additional layers have a requirement to be semi-transparent so that the user can still see the underlying geometry. This semi-transparency was not available in the AutoCAD system and this shortcoming meant that the use of this capability could not be demonstrated but it is readily available in recently produced CAD systems and can be seen in the Parasolid CAD modeller used by Graphics Research Corporation Limited (GRC) in the Paramarine ship design software [Paramarine 02].

Through the development of layers it is possible to capture a large quantity of additional data associated with equipment items. The number of different layers depends upon the type of equipment and the amount of further information it is possible to capture. When developing a model for inclusion into the system it is desirable that all information available should be captured. This may just cover access, applicable to all items, or be more specific e.g. electromagnetic exclusion zones or efflux areas. An example is shown in Section 10.3.1 where design guidance on the location of Replenishment at Sea (RAS) points is shown.

The CAD system must allow access to a list of layers that are present for the equipment items placed within the design space. This list will serve as a prompt to the user, allowing him to see what additional information is captured, and assist in controlling the display.

d) Placement Constraints

In order to allow individual items to be placed in the CAD model and combined with other elements an assembly modelling package, Mechanical Desktop, has been used as an add-on to AutoCAD. This enables the use of individual elements and combinations in an overall assembly, whilst additional benefits could be provided through constraints.

Assemblies can be created by constraining the movement between items, eliminating rigid body degrees of freedom. Each time a constraint is added between two parts one degree of freedom, or more, is eliminated. A fully constrained part cannot move in any direction. Within the breadboard system four types of constraints were present [Autodesk 97b].

Mate –	To join points, planes or non planar faces.
Insert –	To align two circles, including their centre axes and planes.
Flush –	To make two planes coplanar with their faces aligned in the same direction.
Angle –	To control an angle between two planes or two vectors.

These constraints, illustrated in Figure 9.9, have been developed for standard mechanical assembly modelling but are suitable for use in the proposed topside tool. When creating the design it is possible to add appropriate constraints, constraining movement in one or more dimensions. The mate constraint can be used to ensure items sit on the surfaces they are intended to, the other constraints allow items to be aligned in particular directions.

Image removed due to third party copyright

Figure 9.9 : Illustration of CAD Constraints [Autodesk 97b]

Through the use of this breadboard system the requirement for an additional constraint requirement has been identified. This allows one item to be constrained a particular distance from another. This distance should either be fixed, or set as a minimum distance allowing larger separation, but not smaller. This will allow the designer to fix the separation when it is felt necessary from the design guidance given, for example separation between radars, and this will ensure that this distance is maintained as the design develops.

It is important that the CAD system allows these constraints to be applied to equipment items when they are placed into the CAD model. These additional aids help the user quickly place the item where required, for example when placing a gun on the foredeck, the base of the gun can be constrained to the deck, once this is done the user only has to move the gun in the remaining two dimensions. Without these additional aids it is easy for the user to either have trouble placing an item exactly where required or to accidentally move an item from its desired position.

e) Drawing Preparation

Although all graphical manipulation is carried out within the 3D design space within the computer, it is important that the design can be presented as paper drawings. As a result it is necessary for the CAD system to be capable of printing the design to a plotter. This must be as the three dimensional picture seen on the computer screen but also in more conventional format.

A ship design is conventionally presented as a set of deck plans and an associated profile. For the topside requirement this consists of a series of deck plans depending upon the number of decks within the superstructure and a profile view. Where necessary additional views from the bow and stern can be presented. From the information about the design held within the CAD system it must be possible to automate the generation of these drawings. By taking a series of slices through the solid model, the two dimensional drawings can be produced with minimum additional user interaction.

f) Import and Export Features

By using a commercially available CAD system as the basis for the graphical capability of the system, the major import and export requirements will be met. To populate the database existing models can be brought into the system and added to the database. This may apply to individual equipment items or be specific to a particular design where, for example, the hullform may have been designed on another system and will require importing for topside development. Export capability is required, as increased use of CAD systems throughout the life of a ship requires that data can be exported to other systems for further development or for the use of the model in more complex simulations.

Commercial software developers are currently working on the import and export standards for the future. The most common standard to date has been the IGES format [IGES 96], which has been used to transfer data in the development of this breadboard system. The requirement for far more comprehensive data conversion has lead to the development and continual improvement of the STEP format [ISO10303 01]. This allows far more associated data to be exported along with the graphical description. What is important in the context of this work is that the graphics kernel used for the development of any system must be compatible with these standards and supported in such a manner so that as developments to the graphics package are made they can be incorporated into this specific topside design tool.

9.3.3. Visualisation Requirements

One benefit of developing the model using a 3D CAD system is that it provides access to the information required in order to produce animations and publicity pictures. This is very important for projects as they develop and time is spent creating presentable graphics of the design, as it evolves, to present to the Project Manager and to potential users of the design. It is also vital to assist decision making with customers, naval staff and users. Through use of the proposed system the design work is carried out in the 3D environment with models that represent the real equipment items. As a result it is possible to create presentation material quickly and easily with little in the way of further work. To create a lifelike representation the colour coding used in the development has to be removed and replaced with more suitable colour schemes. This is the only change required and then still or animated graphics can be produced directly from the model under development.

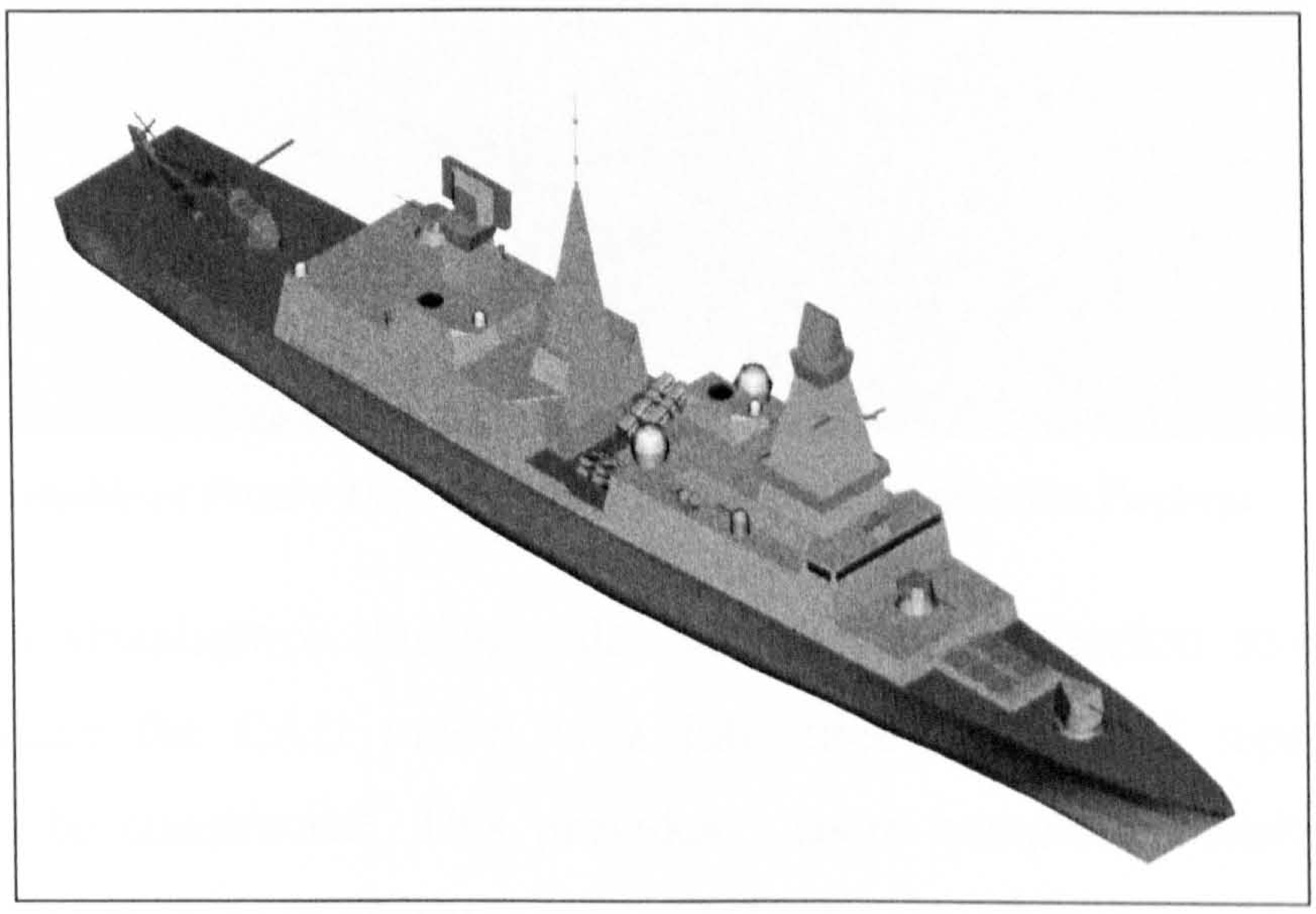


Figure 9.10 : Rendered Visualisation of Future Destroyer from Autodesk Mechanical Desktop

Figure 9.10 shows a rendered view of a typical warship under development. This model was developed, by the author, as part of this research work to investigate the CAD capabilities of the breadboard system and is based upon the Anglo-French-Italian HORIZON design aimed to replace the current UK Type 42 Destroyer prior to the current type 45 design [Van Griethuysen & Juliot, 96]. This figure has been taken directly from the Mechanical Desktop graphics package. It provides a good representation of the ship assisting discussion and presentation. It does not provide the type of picture required for more formal publicity or exhibition. Where this is necessary further work will be required using a visualisation package. The CAD model can be exported to a visualisation package, such as the 3D-Studio facility from Autodesk [Autodesk 90][125], and manipulated to produce more realistic stills and animations. Once the model has been developed in this manner it requires little extra work to add more realistic backgrounds producing a far more suitable publicity picture, this exercise has been performed by the author and the results are shown in Figure 9.11.

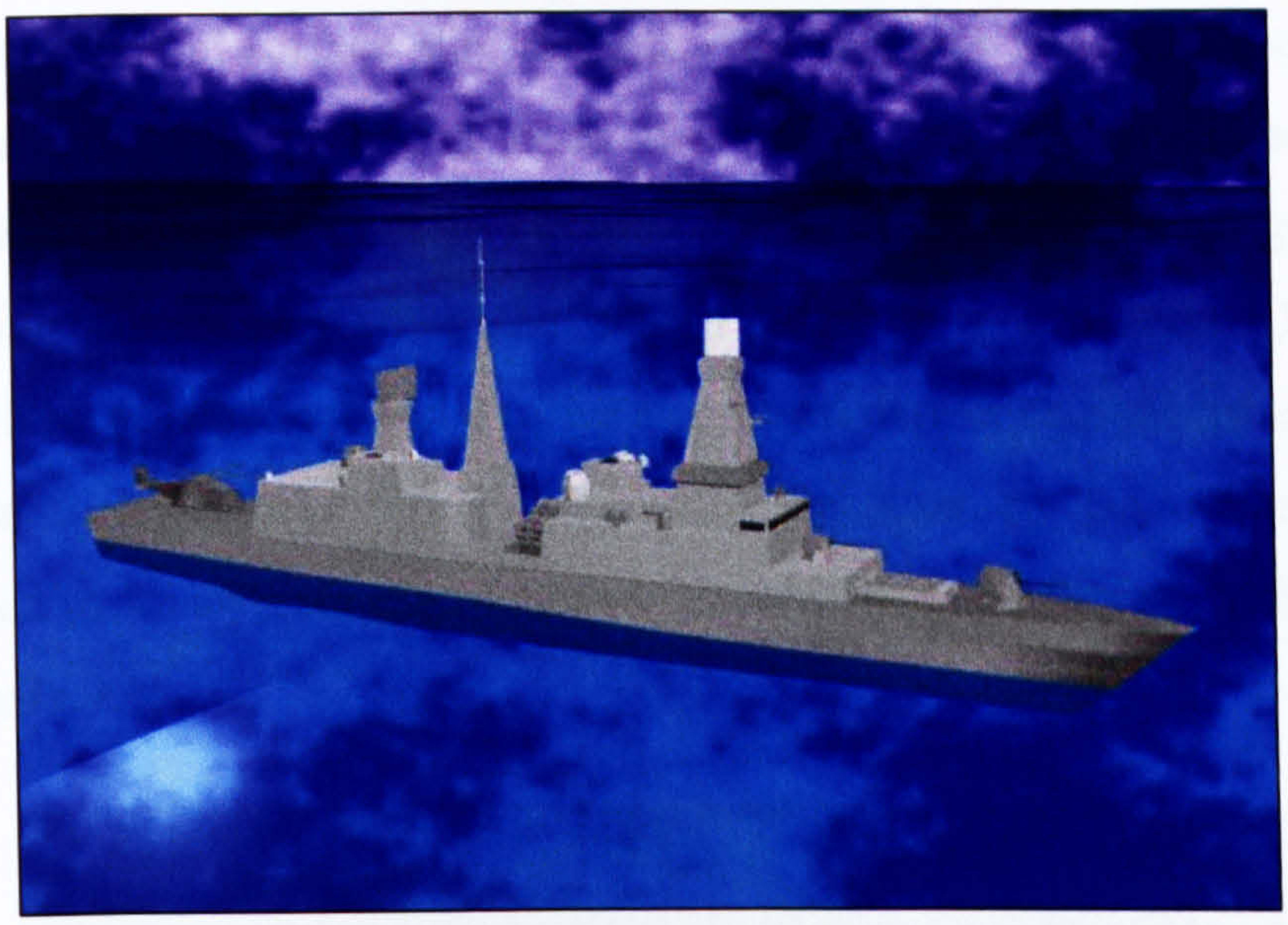


Figure 9.11 : Graphic of Future Destroyer from 3D-Studio Visualisation Package

The use of a visualisation package also allows short animation sequences to be produced. Since the CAD model is a full three-dimensional representation, a flyround can be constructed. This provides a more complete visualisation of the proposed design than a set of still pictures. It is also possible to animate elements of the design to produce more realistic, and moving, pictures. Radars can be set to rotate, weapons can move and aircraft can be shown taking off and landing. Three such animations have been produced during the course of this work and used to prove the added benefit obtained when presenting design work and are included as Appendix 9.

[125] The version of 3D studio used for this research was an early DOS based copy from 1990. Whilst not being the most up to date piece of visualisation software it did integrate with the AutoCAD models produced and allowed exploration of the type of result achievable.

The first of these (Appendix 9.1) was created to illustrate a submarine design produced as part of the submarine course run at UCL [Pompei & Whatley 95], [UCL 95]. This was the first use of any visualisation system and was carried out before the breadboard system and solid modelling techniques were used. As a result the model was created from scratch and was very time consuming. Once the model was created the visualisation package was used to create a short animation used as part of the final design presentation for the design.

The second and third animations produced were directly linked to this research work and were based around surface ship designs. The aim was to investigate how easily an animation could be produced once the model is defined and to show the usefulness of the technique through the use of the animations at formal presentations and for design discussions when the design is in early evolution. One of these (Appendix 9.2) was based around a trimaran aircraft carrier ship design carried out at UCL [Skarda & Sunilkumar 98] (Figure 9.12), the other, by the author, around the design created to investigate the modelling capabilities and shown earlier in Figure 9.11 (Appendix 9.3).

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Figure 9.12 : Animation Still of the Trimaran Aircraft Carrier [Skarda & Sunilkumar 98]

Figure 9.13 shows a series of stills generated from the animation of the future destroyer design.

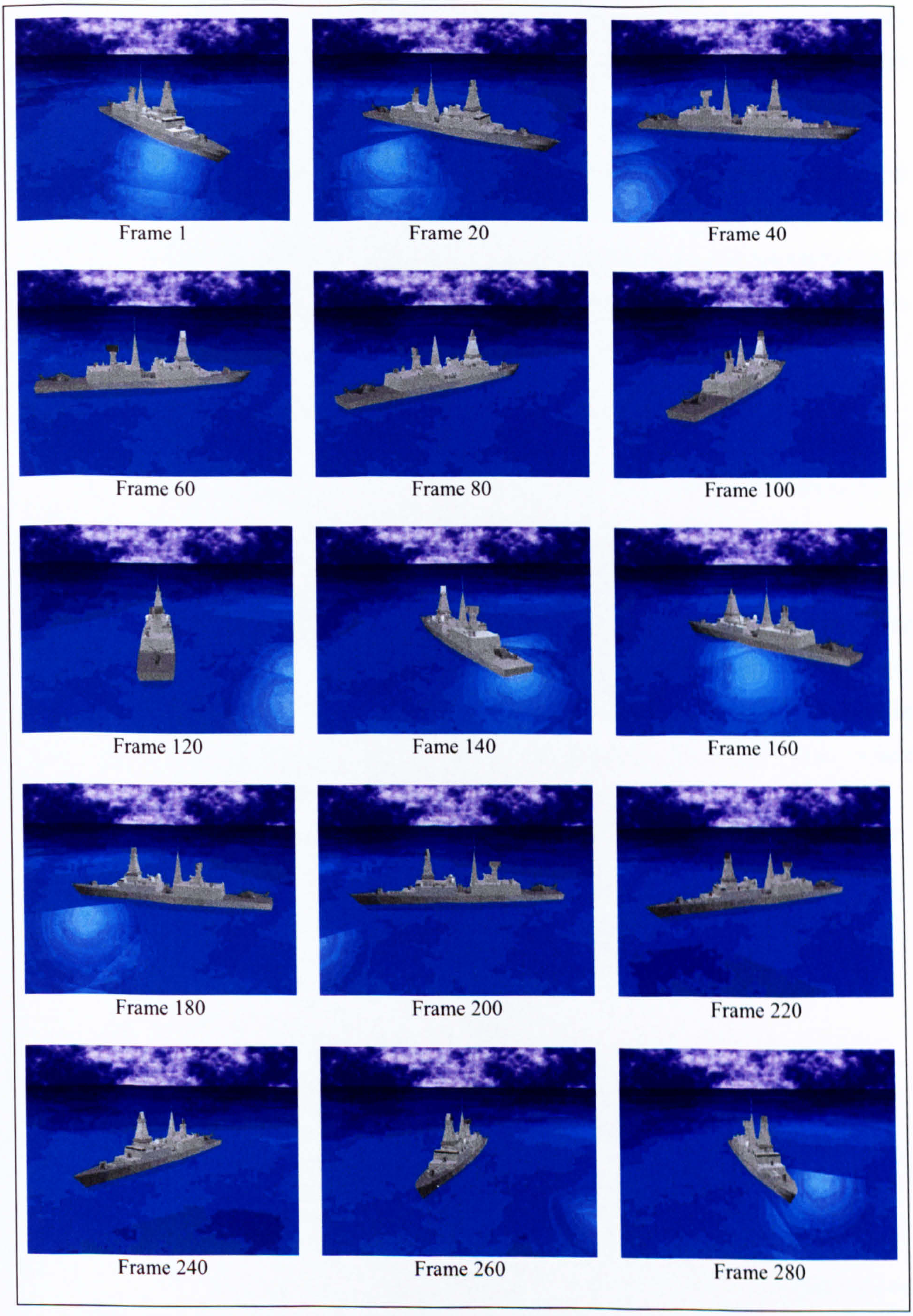


Figure 9.13 : Stills taken from the Future Destroyer Animation

This 300 frame animation was set to run at 12 frames per second resulting in a 25 second flyround that could be looped and used as a backdrop for any presentation. The figure details every 20th frame of this animation and shows how all views of the design can be shown in a single simple animation.

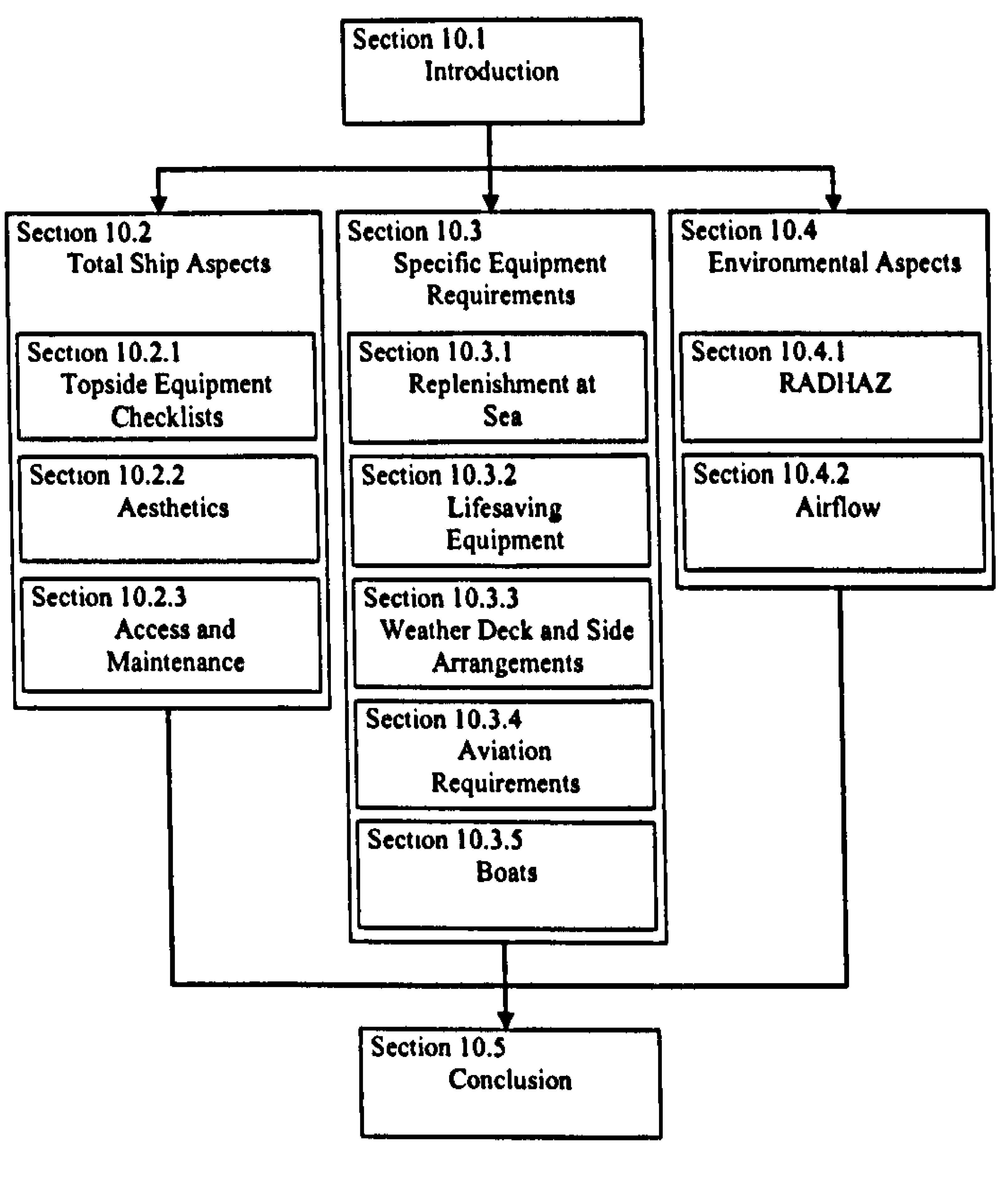
What has been demonstrated is that once a model has been defined, the creation of an animation sequence is a fairly simple task, but the added value to the project can be significant since animations can provide a visual centrepiece to any presentation as part of the design evolution to members of the design team and to a wider, non technical, audience.

9.4. Conclusion

It is proposed that commercially available software is used for the development of both the database and the graphical elements of the proposed system. The choice of software will depend upon achieving the requirements of this proposed system. The implementation of this system is not possible without specific developments being made to both the database and graphics software that is currently available. These developments are becoming simpler to implement due to the more open structure of programs available commercially and the increased flexibility with which modifications and enhancements can be programmed[126].

[126] A good example of the use of a standard graphics kernel for the development of bespoke software is the Paramarine ship design package from GRC. The Parasolid graphics kernel has been combined with a programming language and user front end to enable the development of a specialised tool [Paramarine 02]. Paramarine is already the basis for the practical application of the SURFCON approach [Andrews & Pawling 03], [GRC 03].

10. BASIC TOPSIDE DESIGN GUIDANCE



10.1. Introduction

There are several aspects of topside design where simple design guidance can be given to the designer through use of the design framework described in Chapters 8 and 9. This chapter contains details on these areas of basic design guidance and indicates how it is best provided. The aim of the proposed topside tool is to allow the designer access to all of the available tools but allow design analysis to be carried out at whatever point in the process the designer wishes. The basis for the implementation of these tools is to propose a solution, analyse and iterate as required, looking at the conflicts with other equipment, overall ship aspects, ship features and evolution of the whole design. It is important that the designer is able to use the topside tool to balance all of the conflicting requirements for the design in question, given that the result will always be a compromise. The proposed topside tool exposes many more of the issues that need to be considered in order to inform the decision making than current design approaches at the preliminary design stage. The tools presented here are not an exhaustive list and the proposed framework for the methodology will allow for the introduction of different tools as a need arises. No decision support systems are proposed as these may over-constrain the designer in the design work being undertaken. It is important that the designer has as much control over the design process as possible. The aim of the proposed topside design tool is to enhance the capabilities of the designer during preliminary design but in no way dictate any design decisions. The availability of this guidance to the designer must be instantaneous and automatically updated as the design evolves, providing immediate indication of possible problems and a means to evolve the design consistently.

The topside environment on any warship contains not only equipment specifically carried to perform the particular military role as a warship but also other items of equipment required to safely and effectively operate the ship. It is also important to consider how the placement of all individual pieces of equipment will affect the total ship topside environment. These concerns are often overlooked in the early stages of warship design. Guidance exists, mainly within the UK Naval Engineering Standards [DEFSTAN 00], for most of these items and the important issue for topside design is for the designer to consider these items at the same time as placing major combat system equipment. These, other than combat, aspects can have a significant impact, either requiring other equipment to be moved in order to accommodate them, or more significantly requiring redesign of the superstructure in order to allow for their placement.

The proposed tools that enable basic design guidance to be provided have be broken down into the broad categories shown below.

- Total Ship Aspects
    - Topside equipment checklists
    - Aesthetics
    - Access and maintenance
- Specific Equipment Requirements
    - Replenishment at sea
    - Lifesaving equipment
    - Weather deck and side arrangements
    - Aviation requirements
    - Boats
- Environmental Aspects
    - RADHAZ
    - Airflow

10.2. Total Ship Aspects

This section on total ship aspects considers those tools that allow design guidance to be given on the emerging topside design. They are not specific to a particular requirement or an individual equipment but are a result of the complete topside environment.

10.2.1. Topside Equipment Checklists

One of the major issues associated with preliminary warship design is maintaining control over the design as it evolves. The use of a broad level of guidance will result in much of this task being performed with reference to the computer. This can be achieved by incorporating a checklist system which draws upon the system database, previously outlined in Chapter 9, for information.

The designer makes some basic design choices when first setting up the project. The choice of type of ship can be used to invoke a standard list of equipment that is applicable to the ship type in question. A default set of required equipment can be shown, allowing the designer to add additional equipment types or remove those that are not required for the design being produced. The choice of definition level will be either high or low (as discussed in Section 8.1) and will require the designer to modify the list to include or hide those elements that are inapplicable.

The checklist will be automatically updated as items are taken from the database and placed into the design space. This checklist can be consulted by the designer at any time during the design process. It will show which equipment items have been placed and which of those that were specified at the start are still to be placed. The checklist system will thus help maintain control over the design and provide an aide-memoir for the designer

Due to the large number of equipment items that have to be fitted to a warship topside, it may be sensible to prioritise the order of layout in order to ease the task. Some investigation has been undertaken as to whether a suitable prioritisation could be produced. For a typical frigate the order shown below seems to be appropriate based on the warfighting role of the ship.

1. Mission related features and their associated support elements
2. Ship self defence features and their associated support elements
3. Communication suite and antennae
4. Navigation features
5. Miscellaneous ship features

This prioritisation is essentially a warfighting priority and although it appears appropriate for topside layout prioritisation, it has drawbacks. There are likely to be items in each of the five groups listed above and all have to be placed. Although the mission related items have the highest direct significance to the warfighting capability, if there are miscellaneous elements requiring placement that will have a major effect on the topside layout then they can become an additional overriding constraint. An example of such a case is in the placement of lifesaving equipment[127] or boats[128]. A large amount of this equipment is mandatory, for ship personnel safety reasons [NES148 92], and must be placed at positions where it can be launched into the water. As a result this will require careful consideration to ensure structure is available at suitable positions. This has a major bearing on the arrangement of the topside and results in such components being given priority.

As a result of this investigation it is not possible to provide a prioritisation order to the user. Choices as to which items have the most impact on the topside remains with the designer and are largely driven by practicability and particular role/mission led drivers. The topside checklist can aid in this task, providing prompts as to which equipment items still require placement. It is also hoped that such a facility as the proposed system will enable the designer to explore options that may lead to challenging conventional practice, with the potential of achieving improved arrangement features and even improve ship configurations.

10.2.2. Aesthetics

The aesthetics of warships also has an impact on the overall layout of the topside. It has been suggested that warships should look as though they can carry out the tasks that they are designed to do [Donnelly 85]. Good visual design consists of individually appropriate details or items which when arranged topside create an impression of balance and coherence from any viewpoint. The layout of the topside of warships cannot be wholly driven by aesthetic aspects but the visual appearance can be improved and hence the validity of the whole design increased through an understanding and application of simple design rules on visual balance and

[127]Although each individual piece of lifesaving equipment is not large there is a requirement to carry sufficient for the entire crew and this has to be placed is suitable positions for crew access and automatic deployment [NES148 92]

[128] Boats can have stringent layout requirements. They have to be placed in a position where, whatever deployment system is used, they can be safely launched. This usually requires them to be located close to the deck edge and for safe operation placed approximately amidships to minimise ship motion during launch and recovery (Section 10.3.5).

coherence together with specialist artistic input [Roach & Meier 79] similar to that possible for merchant ships [Dunn 58], [Guiton 71] and largely without compromising any technical demands [Donnelly 85]. Simple aesthetic guidelines and more involved rules including colour and composition together with practical considerations of visibility and smoke clearance come into play [Guiton 71]. The timing of this input is critical at the conceptual stages where decisions are being made on the overall geometry of the design and therefore the design system needs to provide some guidance relatively early in the design.

A method of measuring visual attractiveness quantitatively has been proposed using an aesthetic cognitive theory utilising generic algorithms to find an optimum solution [Shinoda & Fukuchi 00]. This approach is explained and demonstrated for an example cruise ship. This method appears to allow the aesthetic design to be formalised and controlled, however for the application considered in this thesis this type of approach is not sufficiently developed in the more specific and complex application of warship configuration. The topside shape of a warship is far more complex than that of a cruise liner due to it being composed of many different conflicting elements, rather than made up essentially from superstructure decks with passenger needs and aesthetics dominating the choices.

Although aesthetic input may be required, the process of warship topside design is such that it is not possible to force a rule driven aesthetic design. No direct guidance on aesthetics is proposed within the system. The inclusion of some basic guidelines such as the Dunn curve [Dunn 58], [Guiton 71], will allow the designer to see if the emerging topside fits within a visually balanced arrangement (Figure 10.1).

The emerging aesthetics of the design have to be controlled by the naval architect, however he is aided in this task through the graphical 3D representation of the design. This fully rendered representation is such that the aesthetics of the emerging design can be checked and assessed as the design evolves. The use of computer animations allows for the ship aesthetics to be shown to potential customers and users (Section 9.3.3).

Image removed due to third party copyright

Figure 10.1 : Dunn's Outline Envelope [Guiton 71]

10.2.3. Access and Maintenance

Throughout the generation of the topside arrangement it is important to ensure that the arrangement remains workable from a seamanship and ship operating point of view. The topside of any design must not only contain all of the equipment items required for the particular ship mission but must allow personnel access around the ship and access to individual equipment for maintenance. Access is not a specific equipment item but it is the conscious provision of space and is a characteristic of the spatial layout of the equipment. The provision of suitable access is the key to providing a coherent practical layout.

For some equipment items there will be defined access areas required for maintenance and operation. These maintenance envelopes can be added as a graphical overlay to the equipment items. This overlay can then be used to ensure that access is sufficient and no other equipment or structure impinges upon the maintenance envelope. This is a feature incorporated in many Integrated Product Models (IPM) [Edinberg et al. 96], [Baum & Ramakrishnan 97], [Polini et al. 97] for detailed internal compartment design but needs to be applied to topside deign, albeit in a relatively broad manner.

There are many differing requirements for access, some of these can be considered everyday evolutions, such a standard personnel movement around the ship, others are special considerations, such as escape routes. The range of access requirements is indicated by the following list.

- Routine personnel movement (watch changes, general movement)
- Storing (both RAS and stores to ready use/workshop spaces)
- Equipment removal routes
- Firefighting
- Damage control
- Escape and rescue
- Visitors (diplomatic guests and military and civilian disaster relief)
- Line handling
- Harbour operations
- Deploying equipment (including boats, aircraft etc.)

General access requirements are a function of the overall design philosophy. Some designs have superstructure blocks allowing access along both or one side[129], others may have full width superstructure requiring access routes to be housed within the main superstructure block but not in the citadel[130], e.g. the US DDG51 [Janes 01]. It is possible to place access as an item requiring the access routes to be defined within the 3D CAD model resulting in a exclusion envelope for equipment. In addition, control can be maintained by ensuring that the equipment items and their associated overlays do not impinge upon the planned access routes. In cases where there are access conflicts early definition of suitable routes will help assist in ensuring clearways are preserved as the topside design progresses.

In addition to ensuring that access is satisfactory there are additional equipment items associated with the access route and clearways that themselves may further

[129] Access routes along the ship side on 1 deck can be seen on the Type 23 Frigate and the Type 42 Destroyer. On the Type 22 Frigate access around the full width superstructure is not available on 1 Deck [Janes 01].

[130] The citadel is a section of the ship that can be sealed and maintain an over-pressure through filtered intakes to counter the effect of any chemical or biological attack.

impact on the topside arrangement. As the access routes become more defined the database of equipment can be consulted to add additional elements required for safe access. There is a need for handrails, ladders, guard ropes and other items to ensure that the access routes provided can be safely used.

10.3. Specific Equipment Requirements

A range of basic design guidance can be provided on individual equipment elements, or a set of equipment proved to perform a specific role. Here the guidance provided will aid the designer so that the particular equipment is correctly placed to function at full capability, or that a full set of equipment is suitably placed to fulfil a particular role.

10.3.1. Replenishment at Sea

The requirements for replenishment at sea are given in NES 114 [NES114 88]. Unless otherwise stated, ships normally have four abeam RAS points, two starboard and two port, separated by 25-40m and placed symmetrically about amidships. There is also the requirement for clear areas at these abeam stations to allow for RAS operations by personnel and to recover and remove RAS stores. Data exists on the requirement for the high points depending upon their location. For a given topside design the consideration of RAS arrangement is important from the start of the topside given the specific demanding requirements.

For a non conventional design it may be that the usual approach to RAS philosophy is difficult to accommodate and so early consideration is required. It may be possible to define different RAS point locations but it is essential that these are defined and structure is available for the high points in the locations that is required.

The use of a graphical overlay will allow these rules to be contained within the system and easily accessed using an overlay control. When the RAS point is placed the graphical representation can be added to the design space and constrained to lie on the ship superstructure. In this example it has been placed at the after end of a forward block of frigate superstructure (Figure 10.2).

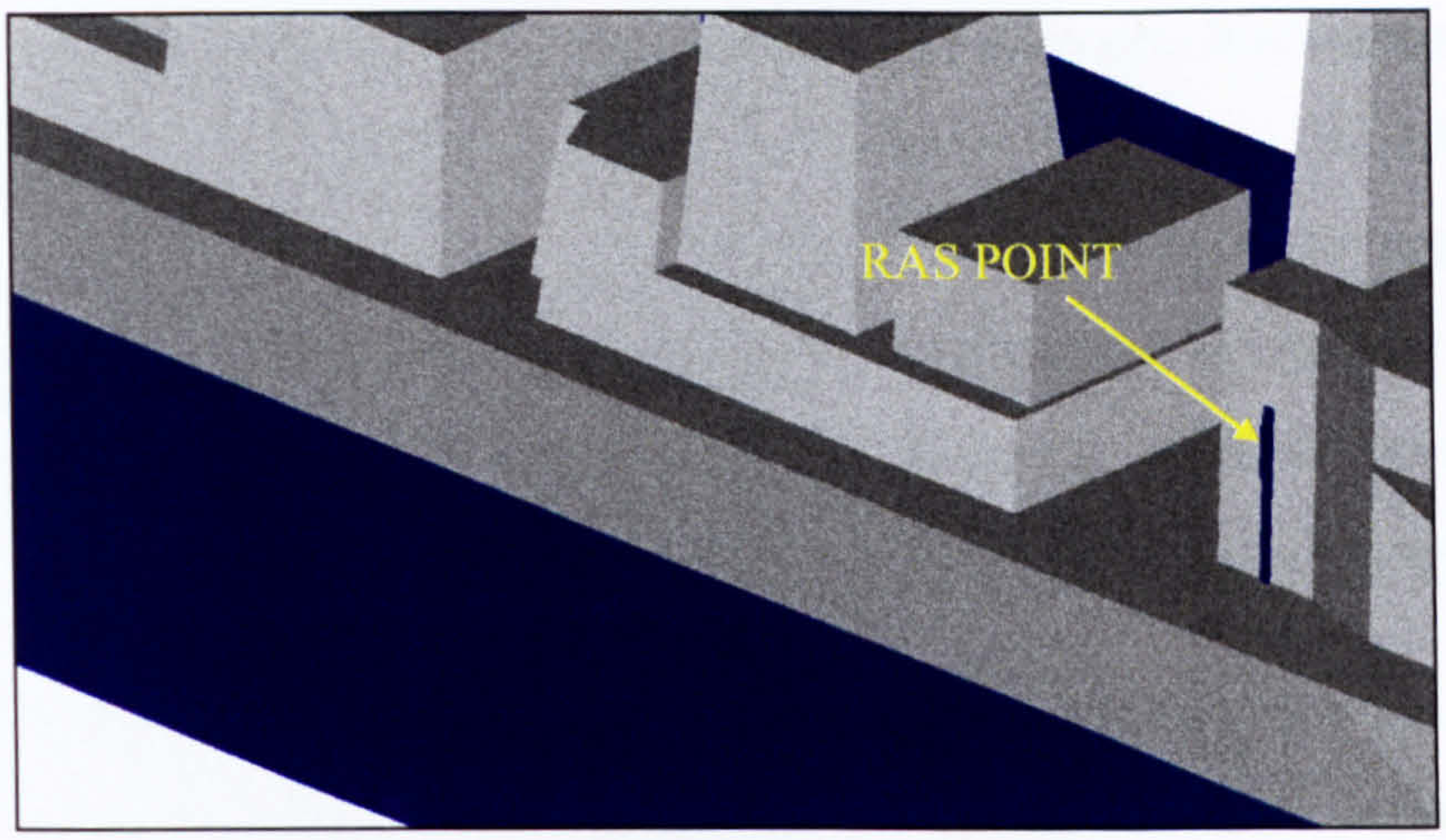


Figure 10.2 : Graphical Representation of RAS Point

The placement of this single RAS point does not initially seem to cause any problems, however the application of the simple rules defined in the NES [NES114 88] can be seen when the RAS overlay is placed (Figure 10.3). Here the graphical definition of the RAS point contains additional information that is only displayed when the user selects the RAS overlay. The graphical representation of the RAS point remains but in addition to this the overlay contains further details on the exclusion envelope required and also guidance on the positioning on a second RAS point[131]. For the final proposed system this overlay would be presented in a semi-transparent colour allowing the user to see if there is an infringement into the exclusion zone.

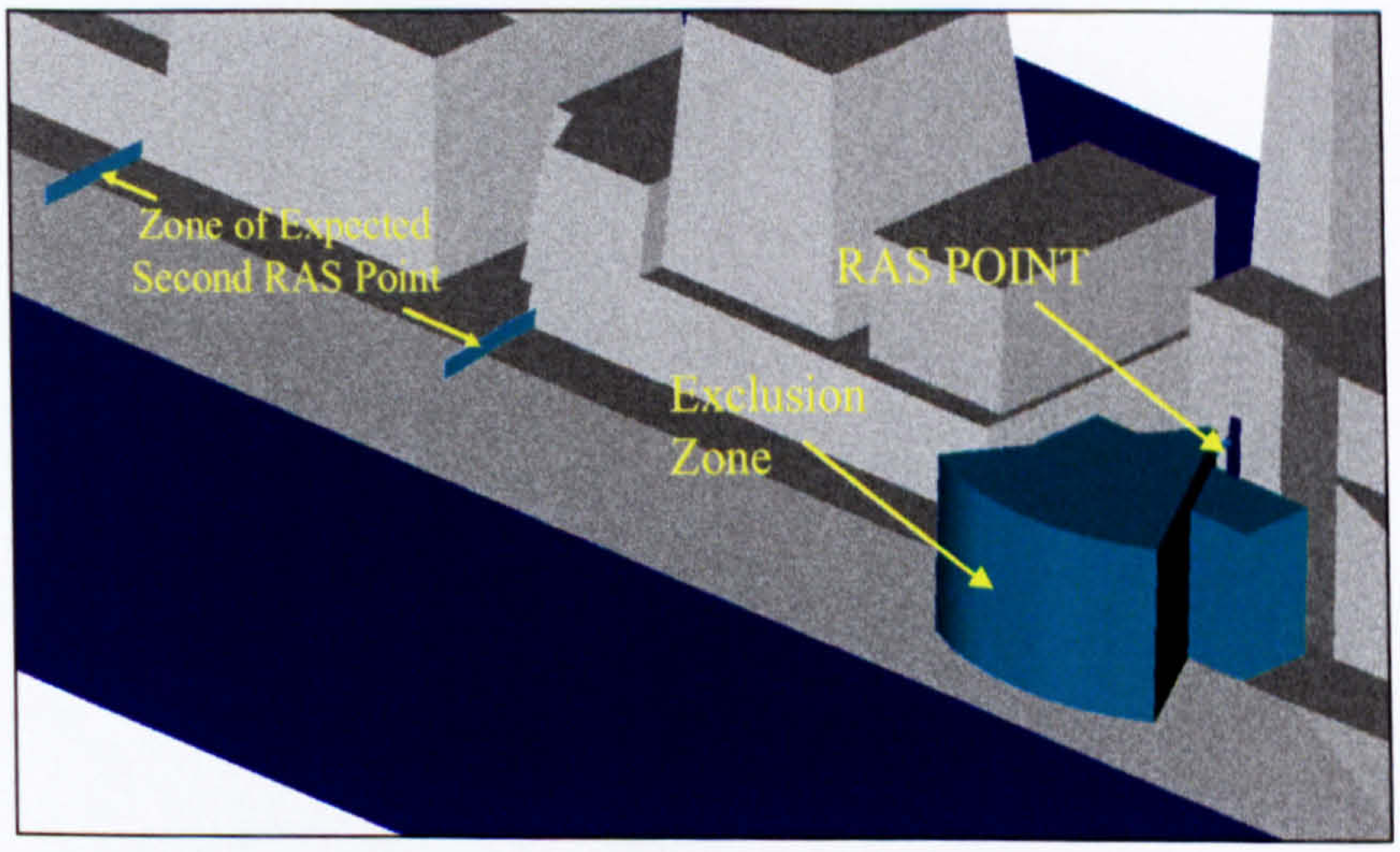


Figure 10.3 : Graphical Representation of RAS Points with Overlay

[131] The exclusion zone consists of the required deck area/access and clearance for the RAS rig wire.

This example also shows the positions suitable for a second RAS point. In this case there is available superstructure and no apparent problems. In addition to the guidance on RAS point separation, the exclusion envelope does not appear to impact upon other equipment. Thus a further RAS point can be added and the requirements of NES 114 met. In the example there is thus no need to investigate other arrangements or to produce justification as to why the NES is not complied with.

Through the use of this overlay there is no requirement for the user to be familiar with the detailed requirements of NES 114. The design rules are embedded into the system and captured for each type of RAS point. The designer is prompted that RAS operation need to be addressed as it appears on the list of overlays available. The information is presented in a clear manner but does not dictate a solution. What it does highlight is whether there is likely to be a problem at which point the user can concentrate more effort on either meeting the requirement or justifying why an exception should be made for a given design.

10.3.2. Lifesaving Equipment

The lifesaving equipment required is detailed in NES 148 [NES148 92] and may have a significant impact on the topside arrangement. It is necessary to provide suitable location and stowage for all the equipment likely to be required in a typical warship [NES148 92]:-

- 25 man inflatable life rafts
- General service lifejackets
- Hazardous duty lifejackets
- Assault troop lifejackets
- Survival suits
- Radio equipment
- Man-overboard smoke and light markers
- Life buoys
- Stretchers
- Rescue station equipment
- Protective suits

Of these equipment items many have to be placed on the ship topside and typical locations can be seen in Figure 10.4 [NES148 92].

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Figure 10.4 : Typical Survival and Safety Equipment Locations [NES148 92]

Some of these equipment items have specific requirements associated with them, most notably the 25 man inflatable life rafts (seen in Figure 10.5 [NES148 92]) and the life buoys. For these equipment items there are requirements that they can be readily deployed over the ship's side. As can be seen the GRP life raft stowage is fairly large and is designed to be mounted on the ship side for easy deployment.

Image removed due to third party copyright

Figure 10.5 : GRP Container Life Raft Stowage and Securing [NES148 92]

In a similar fashion to that described for the RAS points (Section 10.3.1) an overlay can be used to ensure that the placement of the safety equipment is such that ready deployment is possible. This overlay will consist of a combination of an exclusion zone and an aid to location. The location aid will ensure that the equipment is placed in a deployable position by limiting the height and distance from the ship's side.

In the case of unconventional hullforms, the resulting superstructure arrangement can mean that the location of the lifesaving equipment is not as obvious as for a traditional monohull where the superstructure usually allows for fitting of equipment distributed along the length. Layout may cause deployment problems for life rafts and so the designer must consider the placement and deployment of lifesaving equipment and ensure that it can be fitted and operated.

Further design guidance can be given through the use of checklists generated by the system. The designer will have indicated the approximate level of personnel requirements, allowing the lifesaving equipment requirements to be automatically calculated. A checklist can be used to ensure that all items requiring placement have been placed. There is a requirement to provide a certain amount of life saving equipment onboard any warship. This requirement is directly related to the number of personnel expected to operate on the ship. For all equipment items within the system the number required can be automatically calculated. This allows the user to view a checklist that ensures not only all the equipment is added and correctly positioned but also that the correct amount of equipment is included in the design and that access for the crew is coherent.

10.3.3. Weather Deck and Side Arrangements

There are a large number of smaller items of equipment that are required on the topside of all ships. A comprehensive list is given in NES 115 [NES115 84] which also details clearance requirements, ventilation openings, weapon efflux and shore connections.

There are detailed requirements relating to the positioning of all items of equipment including such things as lugs, ladder fittings and eyebolts. These items do not have a major impact on the overall topside design and as such would not be included in the proposed system, they are final design details and need only be considered at the final stages of design. There are items detailed that require consideration, these are the more significant weatherdeck equipment items such as small cranes, anchors and cables. Although these weatherdeck equipment items may appear insignificant compared to the major equipment considered at the concept stage it is important that they are considered to ensure that the evolving design does not prohibit their detailed arrangement later in the design process or that they do not invalidate the choices made for siting major equipment.

It is proposed that the requirements for this equipment be contained within the system through a combination of checklists and overlays. The checklists can be automatically generated by the system to ensure that all relevant equipment is included at the design outset. The use of overlays specific to particular equipment items will ensure that the individual requirements for the item are met. For the majority of weatherdeck equipment this will be a space envelope required for safe operation and maintenance of the item in question. It is not proposed that there would be a specific weatherdeck overlay but that the information contained about weatherdeck equipment would be included as part of an overall access overlay.

10.3.4. Aviation Requirements

For most naval ships the aviation requirement has a major impact on the topside design. For an aircraft carrier the aviation requirement and the layout of the storage areas, hangar and the flight deck dominate the topside [Chapman 60], [St Denis 66], [Honnor & Andrews 82], [Autret & Deybach 97], [Eddison & Groom 97], [Menon & Scheele 97], [Webb et al. 97]. On frigate sized ships the after end of the design can be dominated by the need to accommodate helicopter arrangements [Brown 87]. Alternative approaches such as a midship flightdecks can be proposed [Spragg 95], but little experience of their operation inhibits such a radical approach. Other configurations of ship may have different problems to the traditional monohull, one major advantage of the Trimaran design is the ability to utilise the longer hull length and increased beam and place the helicopter flight deck further forward [Alder 97], [Andrews & Bayliss 97]. This is not how flight decks are arranged on current frigates (Appendix 3) and so careful consideration of the aviation requirements is required to ensure that the proposed design is acceptable to the operators NES 1032 [NES1032 95].

It is important that the designer is aided in his choice of aviation equipment as well as in placing this equipment on the ship topside. The use of the database will ensure that correct equipment is chosen. For each aircraft the user can choose the level of support required and the equipment necessary for this can be automatically added to the checklist of necessary equipment. In this way through a simple choice made on the level of support, for example, whether a land on or organic capability for helicopters is required, the designer will be guided as to the equipment required. In the case of adopting an organic helicopter capability the requirements for the flight deck and the hangar with associated refuelling, recovery aids, capture and traversing systems, weapon loading, fire fighting and maintenance facilities will be included.

For each of the equipment items identified through the choice of capability, the use of overlays indicating exclusion zones and giving guidance to placement will provide additional guidance. Through a combination of automatically generated checklists and the overlays the designer is only required to make an operational design decision and is then aided in all equipment requirements and placement.

10.3.5. Boats

The positioning of boats is often an important topside arrangement feature due to the limited areas that are appropriate for their deployment and safe operation. There is a requirement to carry boats onboard all UK naval vessels[132] and they have a significant impact upon the topside arrangement. It is important that their positioning is considered early in the design as the boat and associated deployment system constitutes a large piece of equipment with very specific requirements.

The most import factor to be considered is the deployment of the boat and so an overlay illustrating the deployment area can be used to ensure that the boat

[132] Boats are used for a variety of tasks including boarding, storing and security as well a safety roles such as man overboard. Further requirements are placed on boats as naval ships now have an enhanced constabulatory role [SDR 98].

placements are such that they can be safely deployed, operated and recovered. This overlay should include both the space required to launch the boat and also the areas required by personal to safely operate any equipment used to deploy the boat. There are a large number of arrangements for both boat storage and deployment. In some more recent designs, such as the French La Fayette Class [Friedman 96], [Janes 01] and the US LPD 17 [MIT 96], [Janes 01] boats have been placed within the superstructure having a sliding door covering the access. Although this results in the boat requirement being contained within the superstructure block it is still a topside layout problem. In this case the features that would have to be placed within the topside design space would include the superstructure within which the boat is housed. This can then be placed within a superstructure block already placed on the topside, or form a new section of superstructure.

In addition to the tools provided as part of the topside design suite, such as graphical overlays to ensure that suitable space is allowed around the equipment for it to be correctly and safely operated, the topside geometry could be exported to more complex analysis tools in a synthetic design environment. Here simulation based design can be used, making use of physics based virtual prototypes to allow the correct and safe operation of the equipment to be investigated [Woodrow et al. 98]. Analysis of this type is not intended initially to be part of the proposed topside design tool as it is currently too computationally intensive, but the ability to carry out offline analysis would provide additional information to the designer about particular points of conflict in the given topside design.

10.4. Environmental Aspects

Some of the topside equipment will have an environmental impact on the surrounding topside arrangement.

10.4.1. Radiation Hazards

Due to the nature of the equipment placed on the topsides of modern warships it is important that the radiation hazards (RADHAZ) implications are considered. Any equipment that emits electromagnetic waves of any frequency may cause potential problems to other equipment, ordnance or personnel who may be in the vicinity when the equipment is operating [BR8537 90].

Exposure limits are imposed, based on the national guidance levels, on the exposure of personnel to radio frequency radiation. This is a significant problem with phased array radars of all types where they are able to keep a beam trained on one bearing, thereby increasing the danger. Precautions have also to be taken to avoid electric shock or burns through touching wires or structures excited by radio frequency radiation.

Personnel exposure limits are applied and result in either exclusion, or limited access zones around equipment. This information can be captured as an overlay to the graphical system. The choice to display this overlay will show the exclusion zones allowing informed decisions to be made on the positioning of the equipment itself, and for surrounding equipment if it falls with the exposure limit zone. This overlay will also highlight possible access problems where the exposure limit zone impinges upon a main access route or area where personnel are likely to be.

10.4.2. Airflow

There are two main aspects that can be grouped under the heading of airflow. The first is the requirement to ensure that the machinery exhaust does not impinge on any equipment items that may be sensitive to heat or the contaminants contained within the exhaust. The machinery exhaust plume will emerge from the funnel and depending upon the temperature of the exhaust, ship speed and environmental conditions travel away from the ship [Baham & McCallum 77], [Conachey & Kidwell 82]. It is possible to predict this air movement but a large amount of detail is required on the exhaust geometry. For this system a series of overlays are proposed that give exclusion envelopes for equipment sensitive to the exhaust. The shape of the plume shapes used for the overlays can be calculated for a typical ship using a combination of experimental data and formulae based on geometry aspects of the exhaust and surrounding ship structure [Baham & McCallum 77]. This will allow the topside designer to chose a suitable exhaust and associated likely plume shape without having to carry out the many calculations and approximations required to perform a particular plume trajectory analysis. These envelopes can be turned on and used to ensure correct clearances are maintained. It is not proposed that complex analysis be carried out online as this would most likely use CFD analysis requiring specialist user input [Taylor & Smith 97]. The geometry could be exported to tools of this type when required. As developments are made in CFD it may be possible to simulate simple flow online. This flow would be seen as an overlay that can be applied to see where it impinges on ship structure or vulnerable equipment.

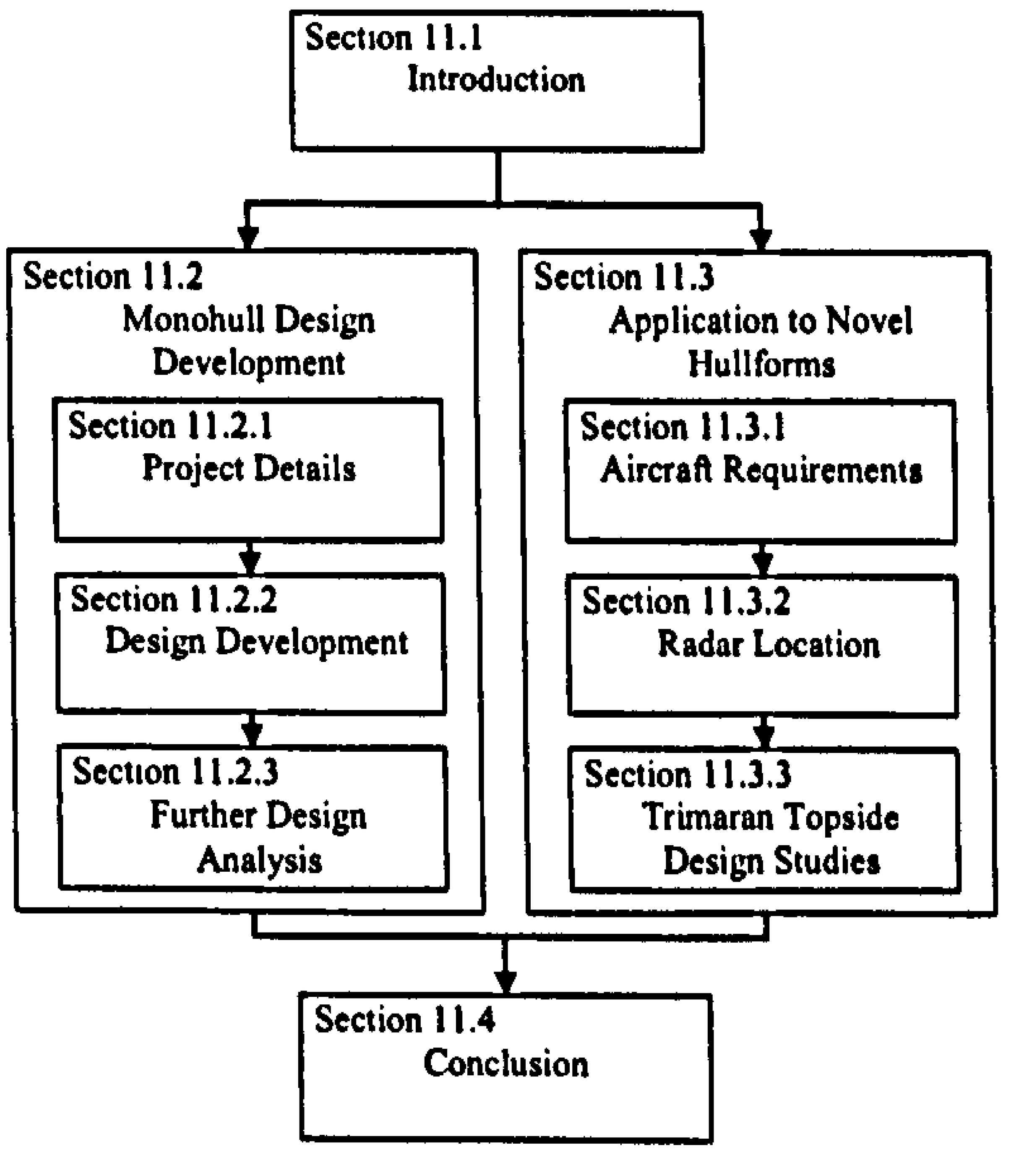
Airflow is also particularly important when considering helicopter operation from the ship. In order to operate aircraft correctly it is imperative that the airflow over the flight deck is suitable for aircraft operations [Taghizad et al. 98], [Wilkinson et al. 98]. Airflow over the flight deck is affected by the main superstructure and hangar of the ship. If not considered, this can create conditions where the helicopter operations are severely restricted. This is a complex task and is most often carried out through CFD analysis backed up with model experiments (Figure 10.6) [Chun 96], [Tattersall et al. 98], [Wakefield et al. 98], [Ramamurti & Sandberg 02]. It is not proposed to initially include any tool of this type within the system but to allow the export of the geometry to allow offline analysis by specialist tools although initial checks by representative overlays might avoid grossly inappropriate topside configurations at the preliminary design stages before detailed analysis and experiment is appropriate

Figure 10.6 : Topside Flow Analysis [Chun 96]

10.5. Conclusion

This section has introduced a variety of different factors requiring consideration during topside design. For all of these items it has been shown that through the application of simple checklists and graphical overlays the designer can be aided in the topside design task. The use of simple graphical techniques in combination with the data stored within the proposed system makes it possible to capture and present a significant amount of design guidance. This removes the need for this detailed information to be held by the designer. The designer can then concentrate on placing the individual items whilst at all times being prompted and guided by the checklists and the graphical overlays holding this information. Once produced, such informed topside designs provide an excellent basis for dialogue with naval staff and equipment/user specialists and provide a better start point for subsequent design development.

11. SYSTEM SIMULATION AND DEMONSTRATION



11.1. Introduction

The individual components of the proposed topside design and integration tool have been defined in the previous chapters and their application to design problems discussed. Throughout the research, use has been made of the breadboard system (Section 8.4) to investigate any proposed tool or method and to determine the data requirements. This chapter contains further details on the use of the proposed design tools and demonstrates how the designer is aided in making decisions through the availability of the methods previously discussed.

Whilst the breadboard system has allowed the development of the methodology it is not suitable to fully demonstrate the system to a potential user. Indeed it is not possible to make use of all the envisaged design tools due to limitations of the breadboard system[133]. The previous chapters have discussed the tools and techniques that would be encompassed in the final tool.

The details presented here are not a step by step record of the evolution of any single design. As the aim is to provide an open design environment where no specific order is required when carrying out a design, such a step by step process is not applicable. Designers are free to use whichever design tools they wish at any point in the design. A number of design issues, related to particular ship design problems, along with explanation of the data available at different design stages are illustrated[134].

The demonstration of the applicability is not limited to the monohull form. The aim of the research (Section 1.2) was to provide a methodology suitable for all forms of surface naval vessel. The later section of this chapter (Section 11.3) details use of the topside design system in the development of ship designs based on novel hullforms.

[133] The limitations of the breadboard system have been discussed in the previous chapters. Shortcomings in the graphical system have been discussed (Section 9.3), as have the limitations of the database (Section 9.2). The discussions on the individual tools and proposed methods have also considered, where necessary, the requirements of the final system to allow final implementation.
[134] All data used has been generated for illustration and investigation purposes only and does not represent any actual system.

11.2. Monohull Design Development

In order to demonstrate the methodology within this thesis a design, loosely based around the Type 23 Frigate configuration (Appendix 3.1.2), is presented. This existing frigate configuration has been used as a proving ground for the system and methodology throughout the development. The illustrations and discussion are based on the development of this simple design, carried out in order to explore the development of the methodology within a known framework. Figure 11.1 shows the design under development using the Mechanical Desktop CAD program (Autodesk 97b).

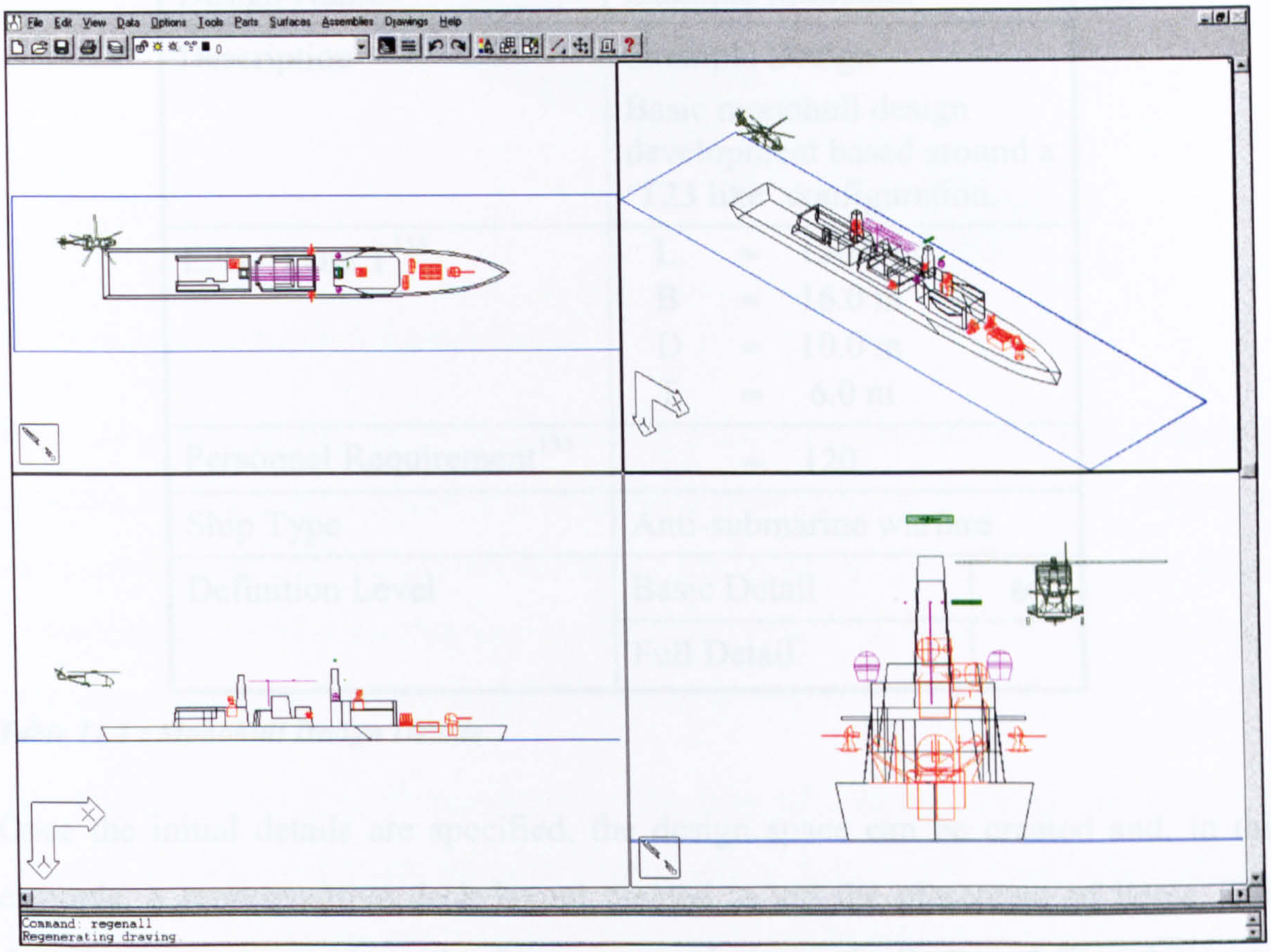


Figure 11.1 : Graphical Model of the Monohull Design During Development.

The figure shows three orthogonal views and an fourth isometric view in which it is possible to render the model, and rotate, to allow better visualisation as the design development progresses. The figures for the remainder of this section show the single rendered isometric view for simplicity, however the other views were used in the production of the study to ease the graphical manipulation tasks required when locating, and constraining, equipment items within the design space. The orthogonal views allow degrees of freedom to be constrained meaning that the graphical descriptions of the equipment items can be located in their required positions through a drag and drop type operation, intuitively achievable within the 3D design space.

11.2.1. Project Details

The design details set at the outset of the example investigation are shown in Table 11.1. These correspond to the items discussed in Section 8.2.3 and match the information that would be provided by the designer when setting up a new design within the proposed topside design system.

Design Name	Example Monohull	
Description	Example Design Basic monohull design development based around a 'T23 like' configuration.	
L, B, D and T[135]	L ≈ 130.0 m B ≈ 16.0 m D ≈ 10.0 m T ≈ 6.0 m	
Personnel Requirement[135]	≈ 120	
Ship Type	Anti-submarine warfare	
Definition Level	Basic Detail	✔
	Full Detail	

Table 11.1 : Monohull Design Details

Once the initial details are specified, the design space can be created and, in this example, a representative deck layout created to aid the placement of items. This deck layout corresponds to the figures entered above (L, B, D and T) and is not a fixed limit for arrangement. The positioning of this deck space within the 3D graphical environment allows the designer to visualise suitable positions for equipment items and to build up the topside layout. If required the dimensions can be changed to accommodate the layout requirements of the topside arrangement as it

[135] For this example design this information has been specified by the designer. For the final system, the integration with SURFCON would allow these details to be obtained directly from the Master Building Block and internal Building Block models under development.

develops. In addition to the deck layout, Figure 11.2 illustrates how a crude upper part of the hull and a waterplane has been inserted. Whilst not required for the topside layout task these graphical depictions of the rough hull shape and waterplane give the designer a better feel for the impact that design decisions have on the overall aesthetics of the ship design in question and allow easier visualisation of some of the constraints on the topside elements, for example boat handling and RAS.

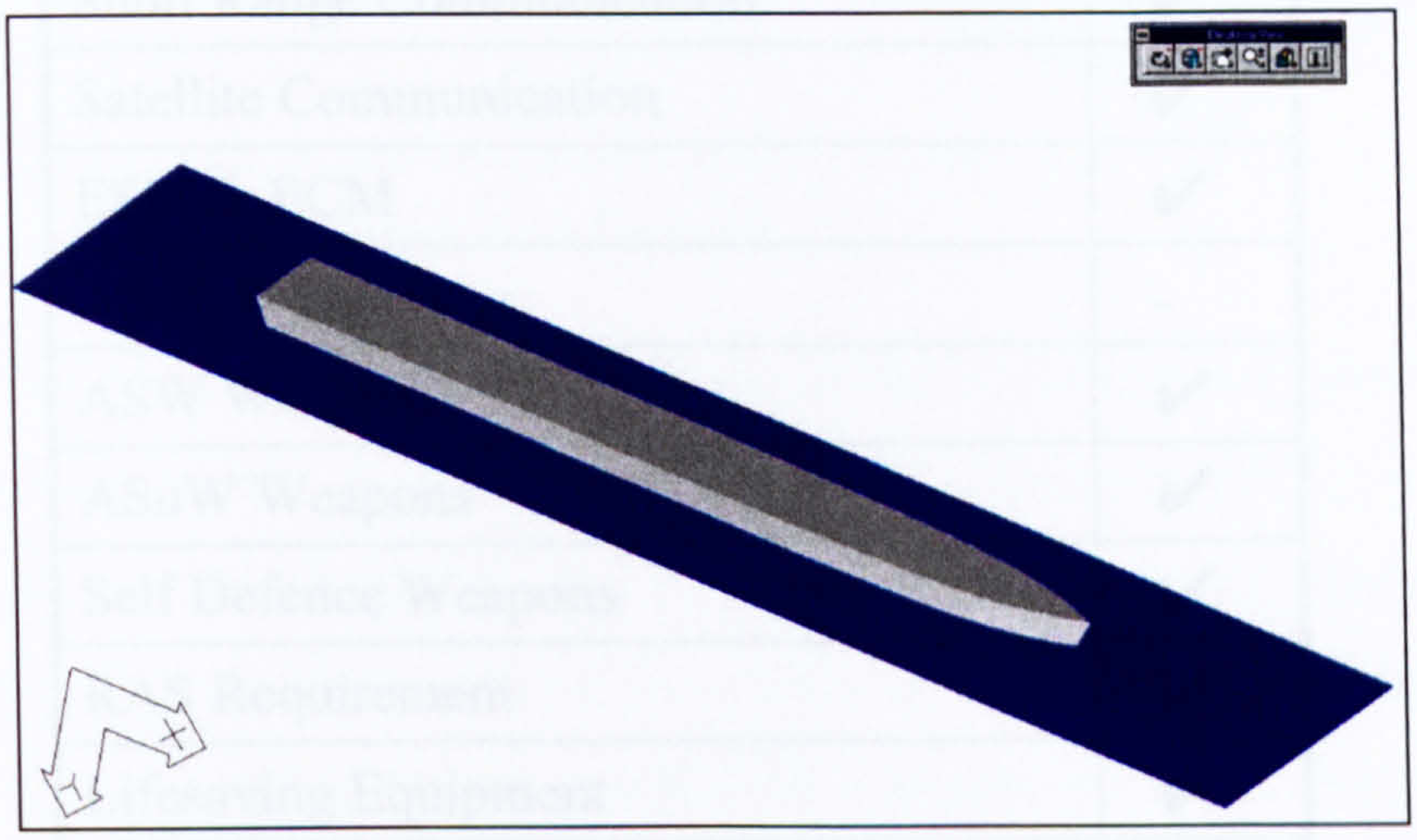


Figure 11.2 : Monohull Deck Representation

From the details entered in the project set-up a checklist (Section 4.2.3) is generated, detailing the equipment items requiring placement (Section 8.2.3). This process is automated by the system but alterations by the designer can be made at any stage. The resulting checklist for this case is shown in Table 11.2, where the ticks indicate a requirement to locate equipment of the indicated type.

The checklist generated[136] contains the majority of elements listed, the design in question aims to be a multi-purpose frigate and so a conscious design decision has been taken to add to the automatically generated list the requirements for long range communication and anti-surface warfare capability.

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[136] The checklist generated for this example contains the major items of equipment requiring placement, but is not exhaustive. As the design progresses the user can amend this checklist to increase the level of detail and include other items that address areas of concern such as access and NBCD.

Air Search Radar	-
Target Information Radar	✔
Navigation Radar	✔
Sonar	✔
Long Range Communication	✔
Medium Range Communication	✔
Short Range Communication	✔
Satellite Communication	✔
ESM & ECM	✔
AAW Weapons	-
ASW Weapons	✔
ASuW Weapons	✔
Self Defence Weapons	✔
RAS Requirement	✔
Lifesaving Equipment	✔
Boats	✔

Table 11.2 : Monohull Design Equipment Checklist

11.2.2. Design Development

The large amount of equipment requiring placement necessitates an investigation to ensure that the available topside length is appropriate [Brown 87]. The anti-submarine role is to be performed by a dedicated organic helicopter capability supplemented by ship launched torpedoes. From the design database a suitable helicopter and flightdeck/hangar arrangement can be chosen and positioned onto the representation of the topside. In this example the hangar chosen includes all space and access required to service the required organic helicopter capability. Figure 11.3 shows these elements placed into the design space, use has been made of the design guides associated with these elements to ensure that the flightdeck is of sufficient size. A further design decision has been made to encompass the torpedo requirement within the forward part of the hangar. This equipment has been chosen from the available database and positioned forward of the hangar. To provide continuity of superstructure the hangar definition has been extended forward, to fully encompass the torpedo system.

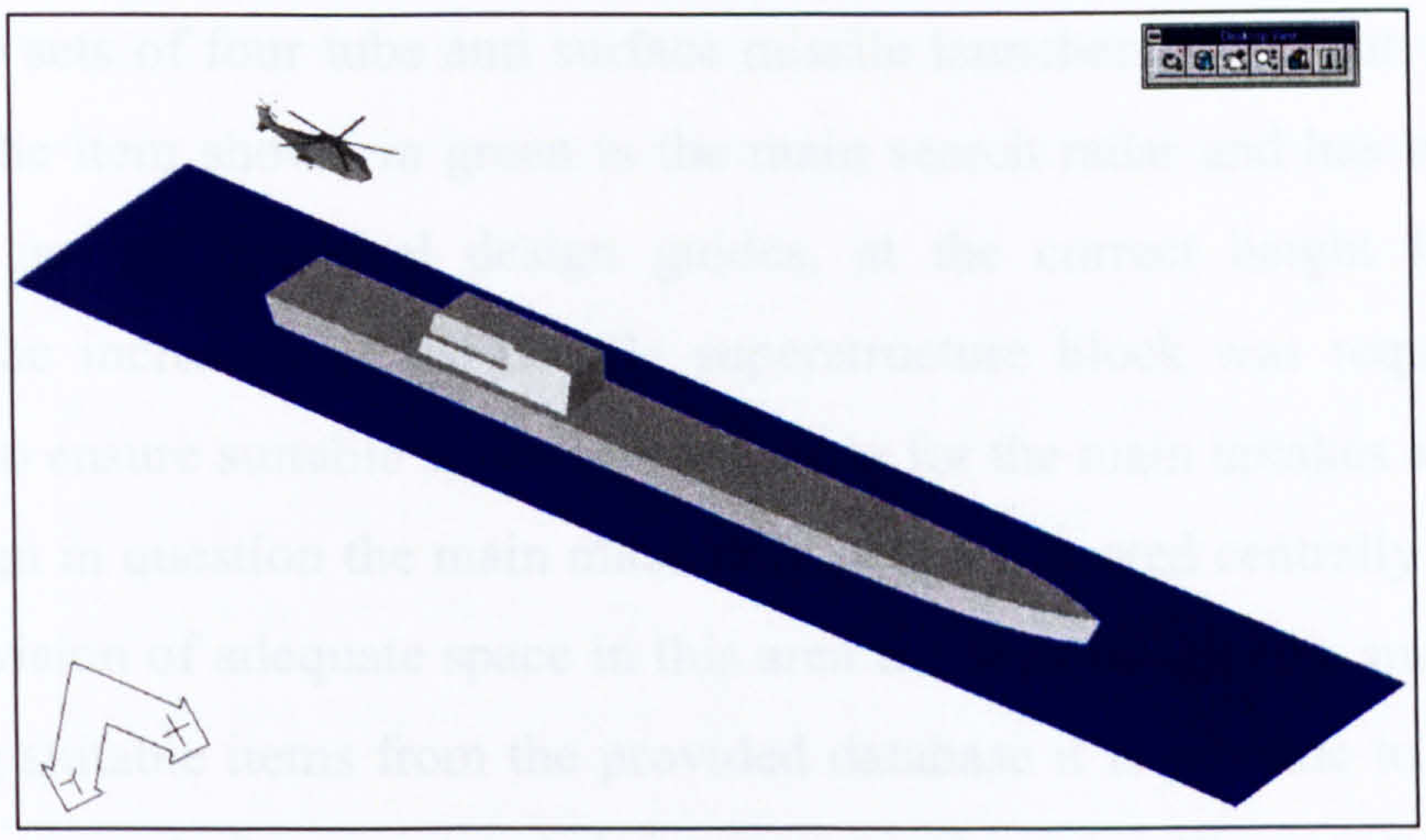


Figure 11.3 : Location of the Flightdeck and Hangar

The positioning of the hangar and flightdeck in this valid position, possible through use of the design guides available as an overlay, illustrates the large impact this requirement has on the design[137]. The next stages of the design work progress the placing of the other items thought of as a priority by the designer. For this design example to ensure a viable layout is achievable within the space constraints it was decided to rapidly place the other major equipment items into suitable positions.

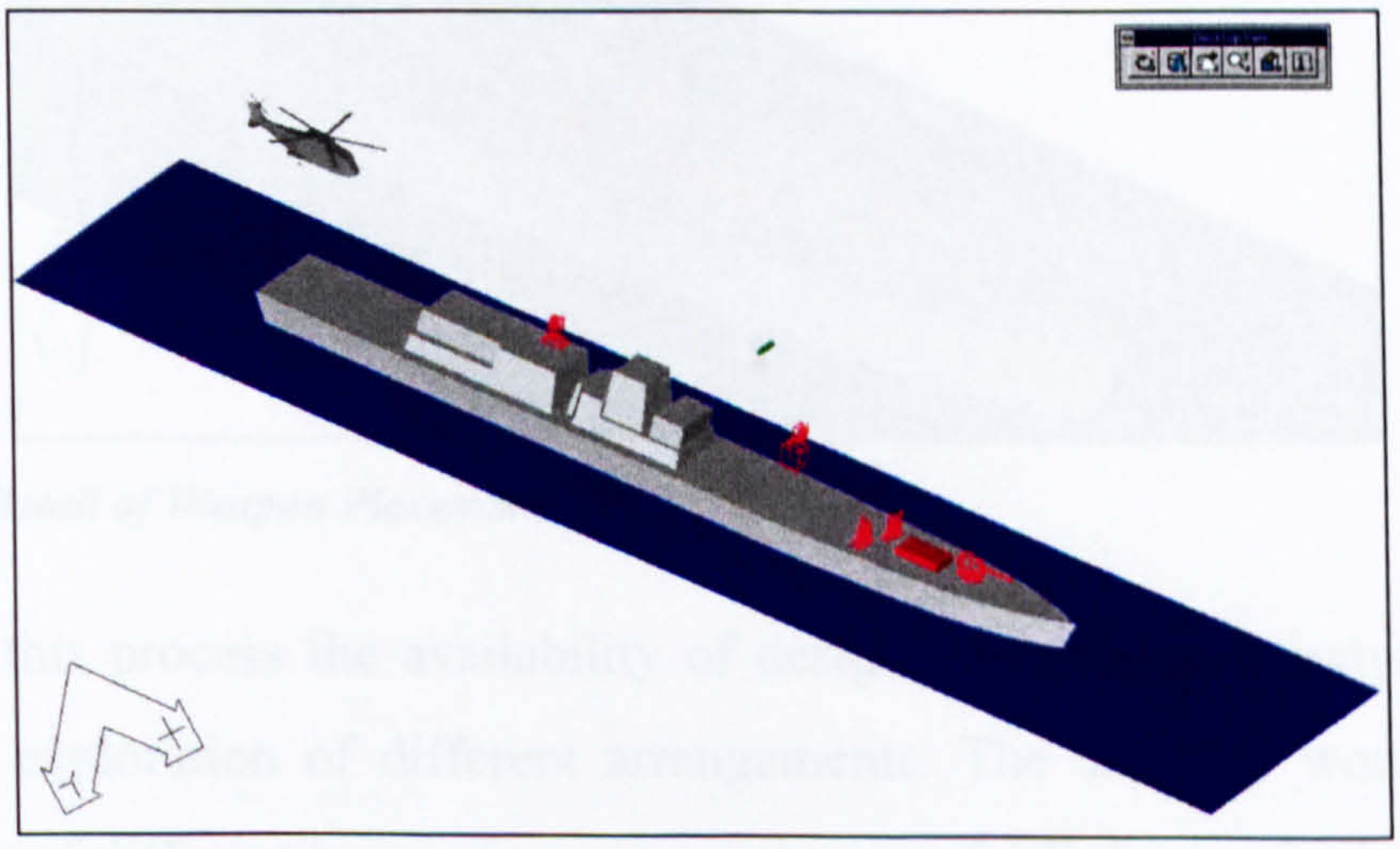


Figure 11.4 : Placement of Major Topside Elements

Figure 11.4 shows this in the 3D design space, the items in red correspond to the chosen weapon systems, in this case two tracker radars and a VLS for self defence

[137] Whilst the validity of the topside design arrangement has been ensured in this study, in a full concept design interaction with the SURFCON system outputs would ensure that both the topside arrangement and the ship internal arrangement were consistent, valid and part of a balanced ship design.

missiles, two sets of four tube anti surface missile launchers and a gun to provide a NGS role. The item shown in green is the main search radar and has been located, through the use of graphical design guides, at the correct height for optimum operation. The inclusion of the middle superstructure block was required, at this early stage, to ensure suitable space was available for the main uptakes and exhausts. For the design in question the main machinery is to be located centrally and so there must be provision of adequate space in this area for suitable uptakes and downtakes. By choosing suitable items from the provided database it is possible to ensure there is an allowance made for associated signature control aspects (Section 6.4).

Figure 11.5 shows a close up view of the forward end of this arrangements showing the combination of solid and wireframe representations that have been used.

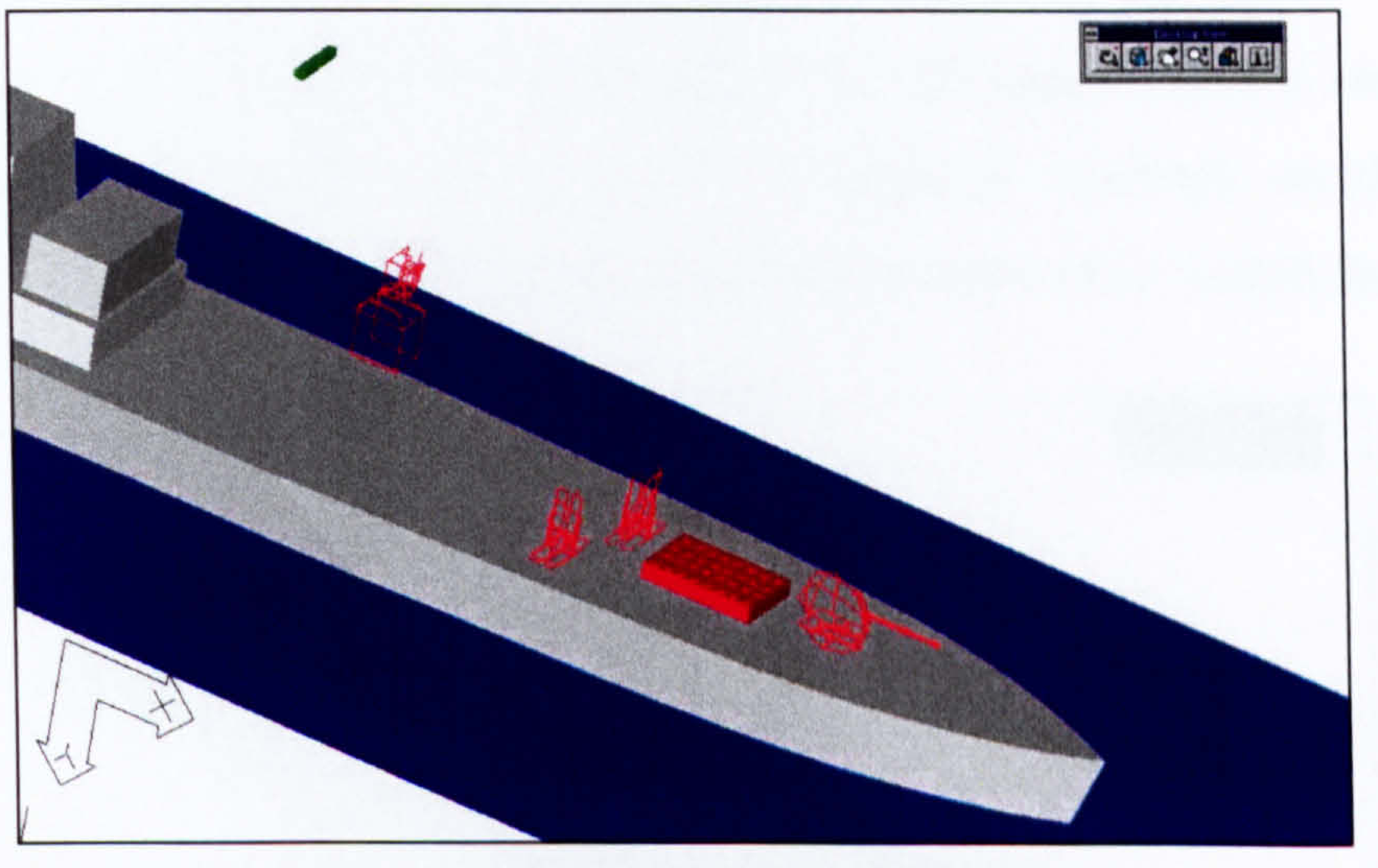


Figure 11.5 : Detail of Weapon Placement

Throughout this process the availability of design guidance and analysis tools has allowed the exploration of different arrangements. The database would contain a large number of different types of weapon systems to fulfil the required roles, and the use of differing overlays would ensure that all placement requirements were met (Section 4.2.2). Graphical overlays illustrating the required clearance and efflux zones would ensure the placement of one system did not impinge on another. Through the use of the BAM and scenario modelling techniques (Chapter 7) the designer has access to a large amount of additional useful design guidance. For all positions in which the items are placed the BAM diagrams produced immediately highlight if there are any vulnerable areas. The use of the scenario modelling techniques allow assessment of differing weapon choices and arrangements[138].

Having positioned the major equipment items there is a need to provide additional superstructure to support these items in the form of superstructure blocks and masts. These blocks are available from the design database and scaleable to allow their dimensions to be matched to the design task being undertaken. In this example there is a need for a forward superstructure block to house the bridge and support the forward tracker and a mast to support the radar. Figure 11.6 shows the placement of these additional structural blocks and it is at this point in the design where consideration might be given to RCS (Section 6.5). This would ensure that there were no major RCS problems in the design. The superstructure blocks could be modified to ensure that there were no primary or secondary reflectors[139]. Use of the design angle returns analysis[139] would allow for all superstructure surfaces to be aligned at a suitable angle to reduce RCS. Graphical feedback on the geometry screen makes it possible to ensure that no major problems exist within the design[140].

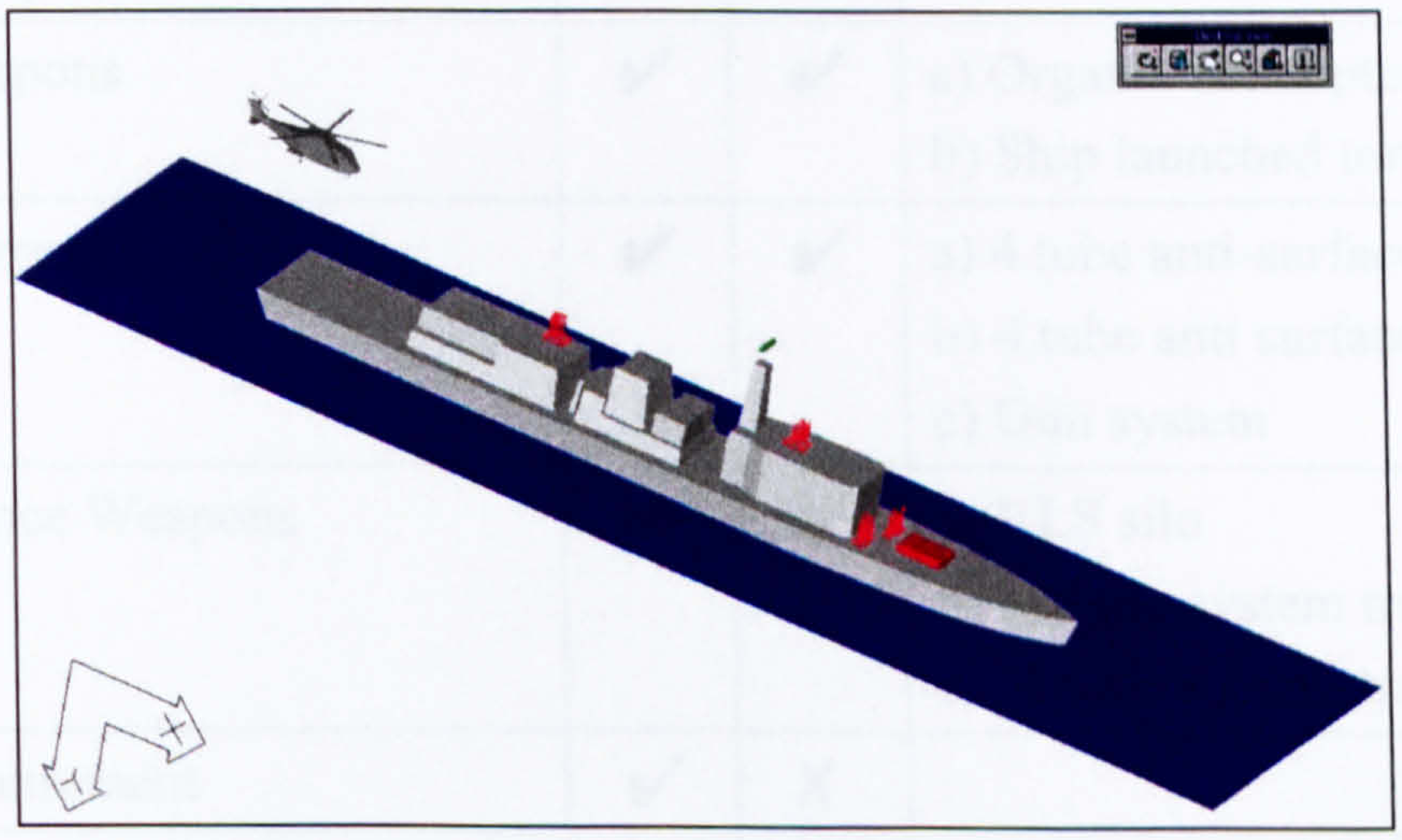


Figure 11.6 : Positioning of Forward Superstructure and Mast

[138] Details of this type of analysis are given in Chapter 7 and are not repeated here.
[139] Refer to Section 6.5.5 for a description of these differing analyses.
[140] This RCS analysis was not carried out for the illustrative design within the breadboard system. The proposed RCS analysis would automatically interrogate the design providing instant feedback on perceived problem areas. Without the automated system it is not possible to rapidly generate the required information, and impossible to show it on the graphics screen of the breadboard system.

Having concentrated on what were considered to be the major elements, consultation of the checklist shows that there are a number of items that have yet to be addressed (Table 11.3).

Item	Required	Placed	Description
Air Search Radar		-	-
Target Information Radar	✔	✔	a) Main search radar
Navigation Radar	✔	✘	
Sonar	✔	✘	
Long Range Communication	✔	✘	
Medium Range Communication	✔	✘	
Short Range Communication	✔	✘	
Satellite Communication	✔	✘	
ESM & ECM	✔	✘	
AAW Weapons		-	-
ASW Weapons	✔	✔	a) Organic helicopter b) Ship launched torpedo system
ASuW Weapons	✔	✔	a) 4 tube anti-surface missiles b) 4 tube anti surface missiles c) Gun system
Self Defence Weapons	✔	✔	a) VLS silo b) Missile system tracker c) Missile system tracker
RAS Requirement	✔	✘	
Lifesaving Equipment	✔	✘	
Boats	✔	✘	

Table 11.3 : Design Report

This checklist facility is available to the designer at all stages of the design and serves as an aide-memoir. The reporting capability of the system is able to interrogate the current state of the design and compare those equipment items placed into the design environment with the capabilities identified at the outset of the project

(Table 11.2). This information is held in the system database and so the generation of the design report is automatic. This reports serves two major purposes, firstly the designer is able to immediately see what equipment items have been placed and secondly it highlights which capability areas have yet to be addressed.

Having established the current state of the design, further equipment was introduced to meet the missing capabilities. Although it proved possible to accommodate all of the major weapon system elements in the available topside length, there remained concern that systems yet to be placed might still necessitate additional topside length. The initial dimensions, used to create the representative deck, were not restrictive and the dimensions could have been modified if necessary. Of the remaining capability areas, consultation of the database of equipments showed that two items could have had major layout implications, namely the location of the communications antennae and the SATCOM system. These elements were introduced into the design space and use made of the available design guidance to position them in suitable locations.

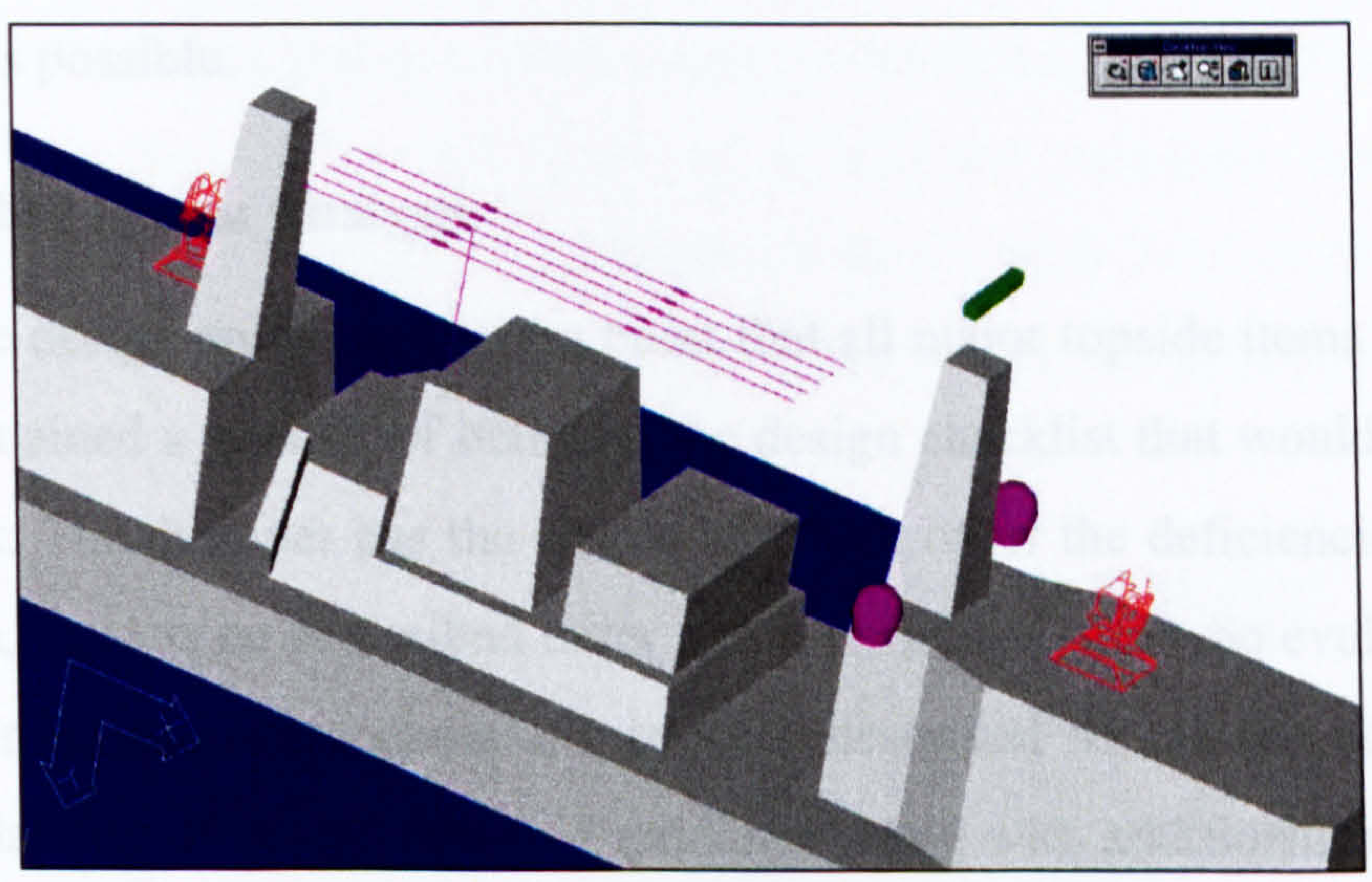


Figure 11.7 : Location of SATCOM and Roof Antenna

For this study it was found that there was no position that would allow a single SATCOM system to have full 360° coverage. Therefore two systems were introduced into the design space and use made of the BAM facility to ensure that the provided coverage was a full 360° with a large amount of double coverage to provide redundancy. The use of an associated graphical exclusion envelope ensured that their positioning did not adversely affect any other systems. The two SATCOM systems can be seen in magenta in Figure 11.7, located either side of the forward mast.

Of the communication antennae required to meet the significant communications requirements the large roof top antenna had the largest impact. By interrogating the system database all of the required communication antennae were investigated to establish what impact they would have. It was possible to manipulate the graphical representation and show that it was possible to accommodate the required antenna length when positioned aft of the mast. This position required the additional support of a mast on the after superstructure. This additional mast could be imported from the design database. Figure 11.7 shows this rooftop antenna system.

At this point in the design there were a number of items that could cause EMI/EMC problems. The interrogation of both the FSUC and the source victim matrix (Section 5.3) would show if there is cause for concern. If there are problems, then either alternative equipment items can be chosen or the details of previous fixes examined to identify if they could be applied, this may require minor modification to ensure the relevant fix is possible.

11.2.3. Further Design Analysis

The example design progressed to the point that all major topside items were placed but there remained a number of items on the design checklist that would still require further work. The designer has the choice of which order the deficiencies should be addressed in, there is no prescribed order and it is the designer who evolves the final topside arrangement. Throughout the process described so far the advantages of having availability of design data and guidance along with additional more detailed analyses is clear. Throughout the remainder of the design work it was possible to revaluate or re-run any of the analyses.

Through the use of the checklist system it would be possible to see which items have yet to be placed. In addition, these checklists contain design guidance within the system. For example, when placing the lifesaving equipments, the system would be informed of the approximate number of personnel and so automatically generate a list containing details of the lifesaving requirements to meet the required standards [NES148 92] (Section 10.3.2).

At some point in the design process the database can be switched from the basic guidance to full guidance (Section 8.2.3). This will allow access to the full database of equipment items rather than the restricted elements initially considered. These more minor elements will also require location within the overall topside arrangement and all of the design tools and design guidance available is equally applicable to these smaller items of equipment. When in the full guidance mode it is still possible to revisit all initial design decisions and make modifications where necessary.

The final outcome of the proposed layout tool would be a detailed three dimensional topside design description. The level of detail achievable is shown in Figure 11.8 where a large number of topside elements are shown, including smaller weapon systems, radars and chaff launchers. In addition to the topside items, use has been made of available superstructure definitions and other structural items, contained within the database, to provide suitable support where necessary. It is not necessary to progress all designs to this level of detail, the proposed system allows investigations to be undertaken at all levels of detail, from very crude analysis of major design decisions to high levels of detail, depending upon the design study in question.

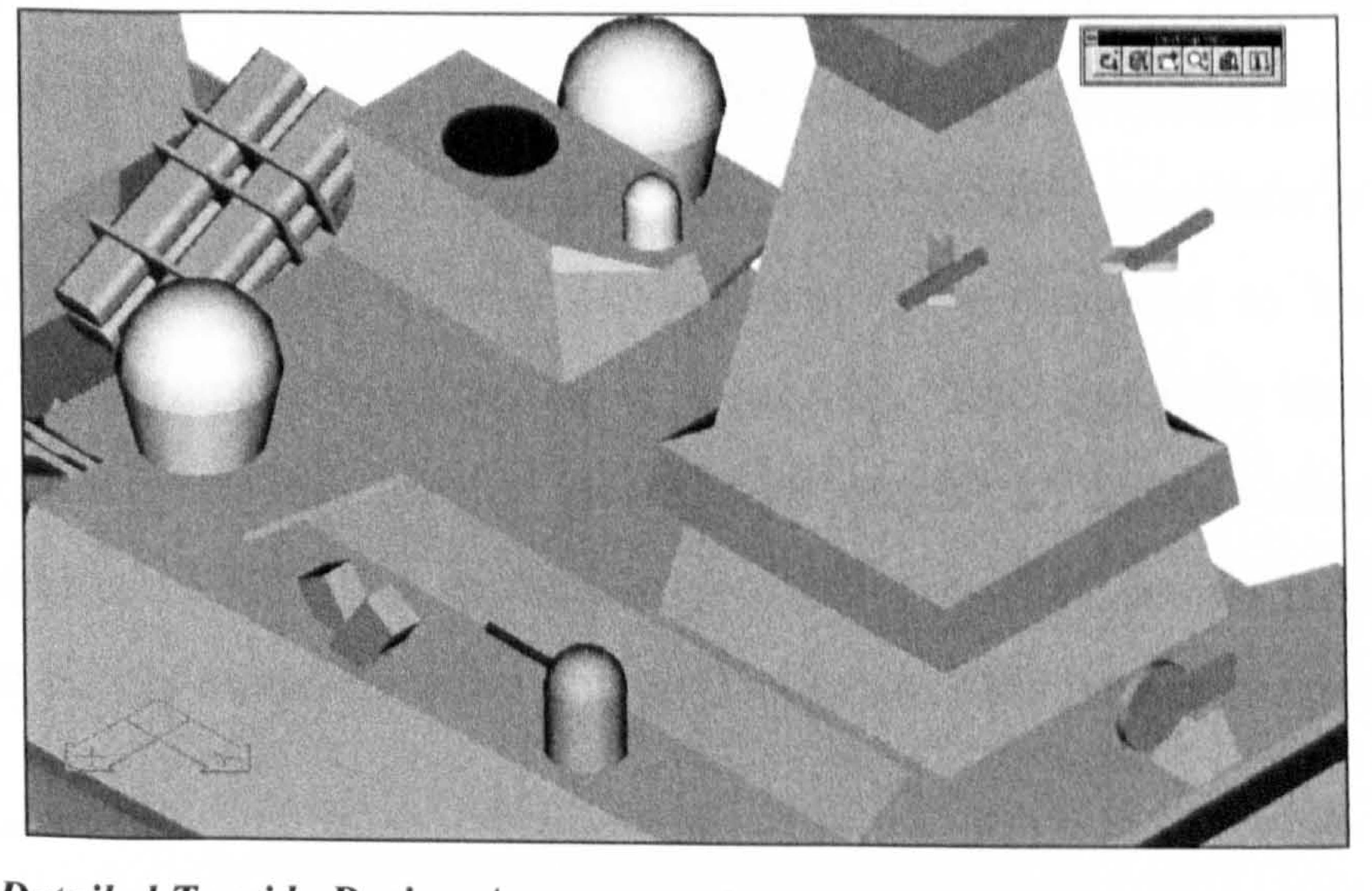


Figure 11.8 : Detailed Topside Design Arrangement

11.3. Application to Novel Hullforms

One advantage of the proposed design methodology is that there is no prescribed order to the design process or design type, allowing the designer to investigate many different ship types and configurations. The requirement for topside layout on these novel configurations is far less well defined and access to the proposed methodology and design guidance should allow investigation of various novel topside layouts. The methodology proposes a 3D design space in which the designer can place any topside element, in any position. Whilst there is no need, during this process, to have a representative hull form, the process is aided by having one. Thus the designer can better picture where equipment items should be placed. As the design progresses there is a need to develop the hull form and the topside arrangement in conjunction with each other [Andrews & Bayliss 98]. This requirement is highlighted through some of the example design decisions illustrated in this section.

The previous section has discussed a number of examples where the designer is aided in the preliminary topside design task through the application of the proposed methodology and availability of the design tools. The following examples demonstrate major design decisions that have to be taken early in the design of more novel hullforms and so influence all others[141]. The availability of design guidance will give credibility to any decisions made and allow further development to be undertaken, in the knowledge that the basic layout is feasible. Two good examples are those of aviation requirements (Section 11.3.1) and radar placement (Section 11.3.2). These two examples illustrate how the availability of design guidance allows for the investigation of differing topside design solutions, particularly relevant to novel hullforms where the topside arrangement does not need to be the largely longitudinal arrangement required on a monohull. Two example designs created during the research to indicate the issues with respect to topside arrangement are shown in Section 11.3.3. The applicability of the proposed design methodology to the particular points raised by these designs is shown. This demonstrates that through

[141] The graphics shown in this section are taken from Paramarine [Paramarine 02] due to the capability of the Paramarine graphics system to contain graphical representations with an associated opacity.

the availability of the proposed topside design tool, the designer will be able to fully investigate novel design arrangements, whilst the design is evolving, with the confidence that no major errors or omissions are made.

11.3.1. Aircraft Requirements

Both SWATH and Trimaran designs have a greater available deck area on which to arrange topside equipment than the traditional monohull. This availability of topside deck area often results in the investigation of different proposed aviation requirements [Andrews & Bayliss 97]. The helicopter and hangar arrangement are a dominant feature on most warship topside layoust [Brown 87] and so the early investigation of feasible arrangements is sensible. Whilst this task can be performed by the designer without access to a system such as that proposed here, the benefits of doing so are illustrated and discussed.

For the example discussed in this subsection there is a requirement to show the impact of differing aviation requirements on the initial topside arrangement for a Trimaran. It has been assumed that there are two helicopter types available, one larger than the other, and that the ideal aviation configuration would be a twin flight deck and twin hangar arrangement, providing full organic capability.

The start point for the analysis is the collation of data regarding the different aircraft requirements. The proposed database would contain this information, unless the aircraft were new in which case it would require some manual data entry[142]. The majority of the analysis requires the evaluation of available space, clearly a graphical task. Figure 11.9 shows how the graphical data contained with the system could be imported into the graphical environment. In the example shown, both the hangar (shown as a cuboid) and the flight deck requirements (shown as a rectangular surface) have been called up for both aircraft options The slightly smaller models (highlighted in magenta in Figure 11.9) represent the requirements for the smaller

[142] If the aircraft were new the details would need to be entered into the system database. This would require a graphical representation and associated data for entry into the database. The designer would be prompted for information required by the available fields in the database for aircraft systems (Section 9.2).

aircraft. The designer now has a clear picture of the differing space requirements and can apply them to the initial design.

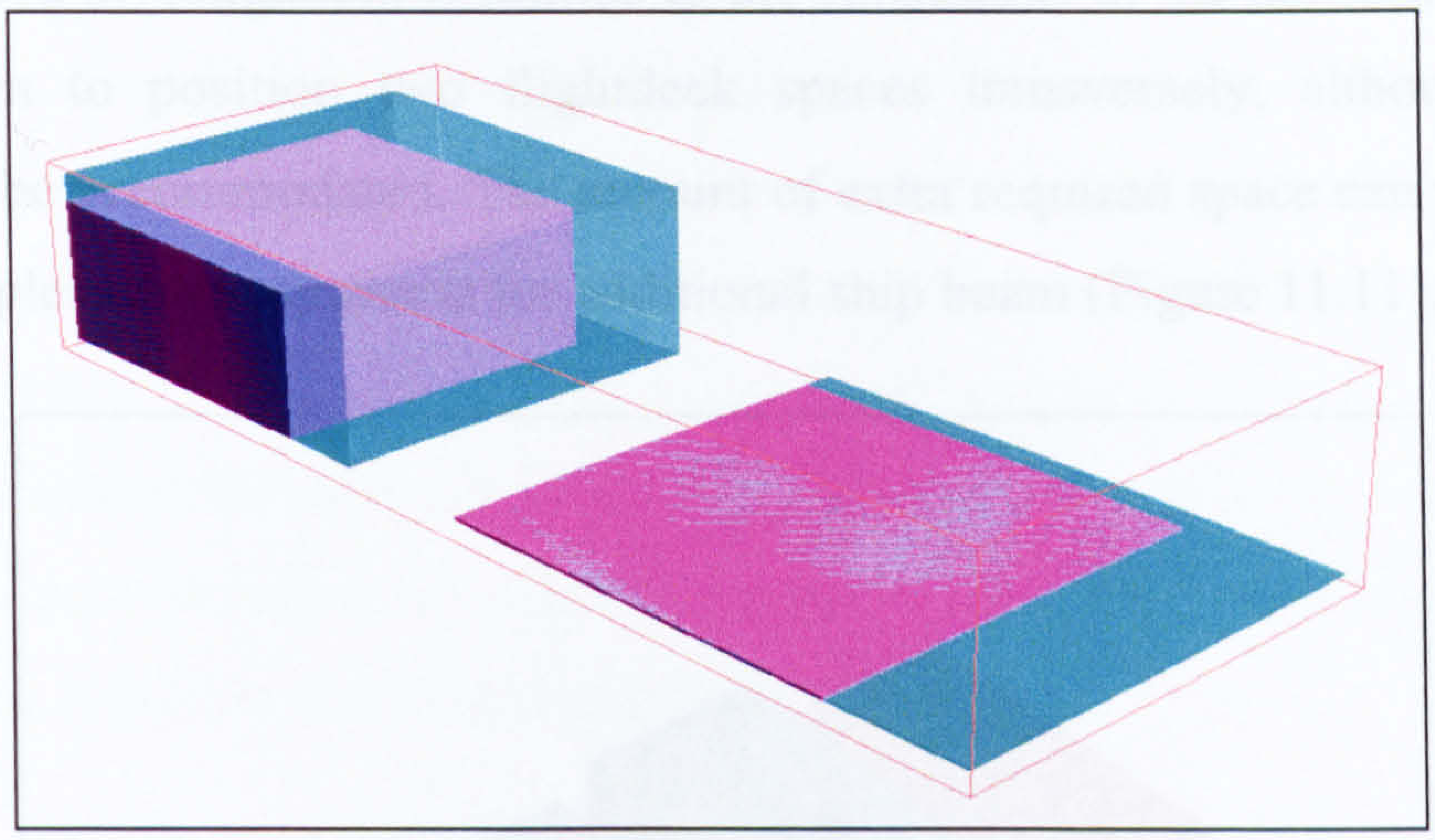


Figure 11.9 : Graphical Representation of Aircraft Requirements

In order to assess the differing impacts, a basis hull is required, this may come from earlier design work, from the SURFCON system, or simply be entered by the designer to allow an assessment of possible impact. In Figure 11.10 the requirements for two of the smaller flight deck spots and their associated hangar spaces are shown on a Trimaran hullform. In this particular example they are located next to each other towards the after end of the cross deck structure where there is sufficient space to have one spot on the port side and the other to starboard.

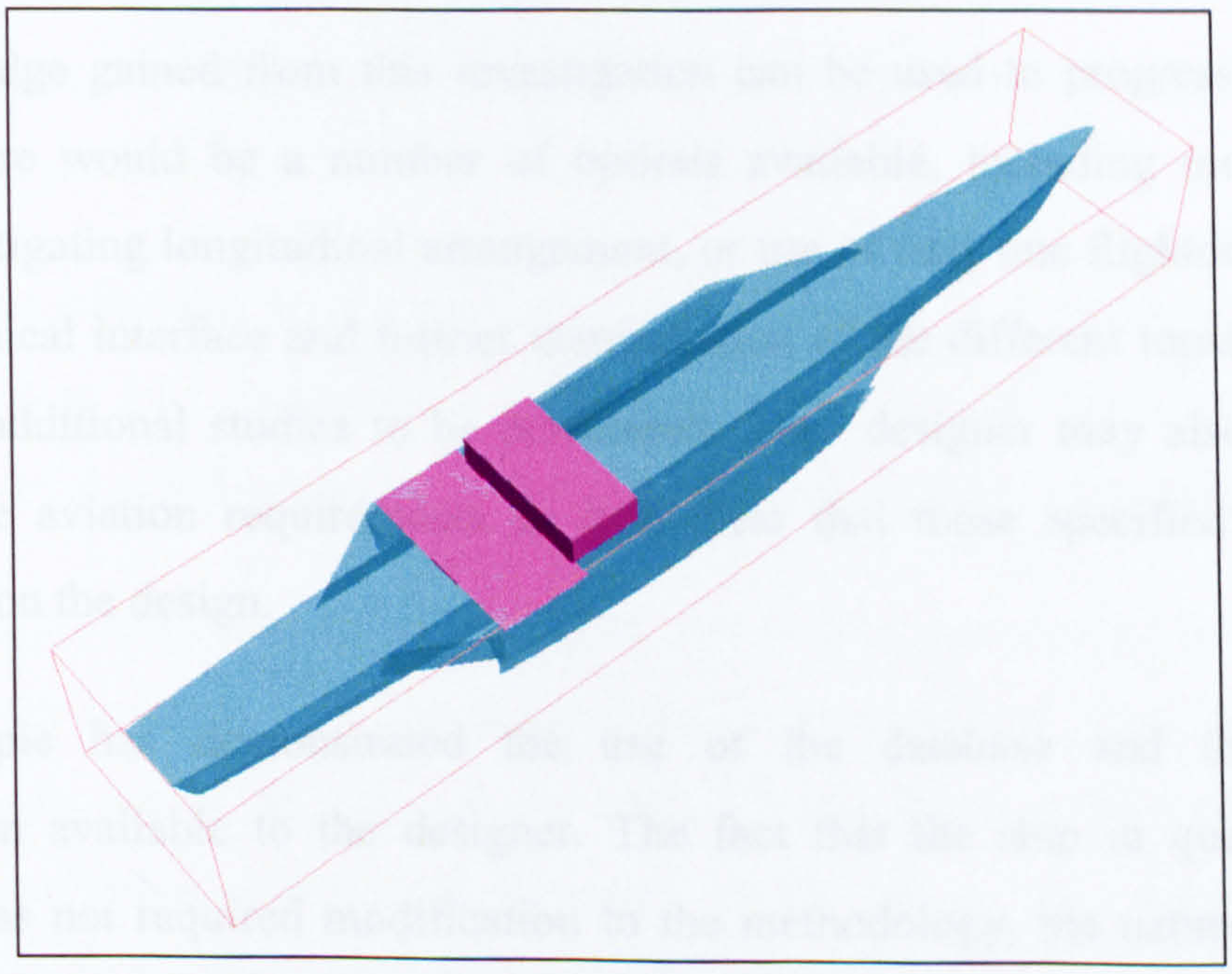


Figure 11.10 : Representation of Small Aircraft Hangars and Flightdeck on a Trimaran Hullform

From Figure 11.9 it is clear that there are greater space requirements for the larger aircraft. The removal of the geometry associated with the smaller aircraft allows further detailed investigation. If limited to the constraints of the hullform there is not enough room to position two flightdeck spaces transversely, although the two hangars can be accommodated. The amount of extra required space can also be seen, in this example as a requirement for additional ship beam (Figure 11.11).

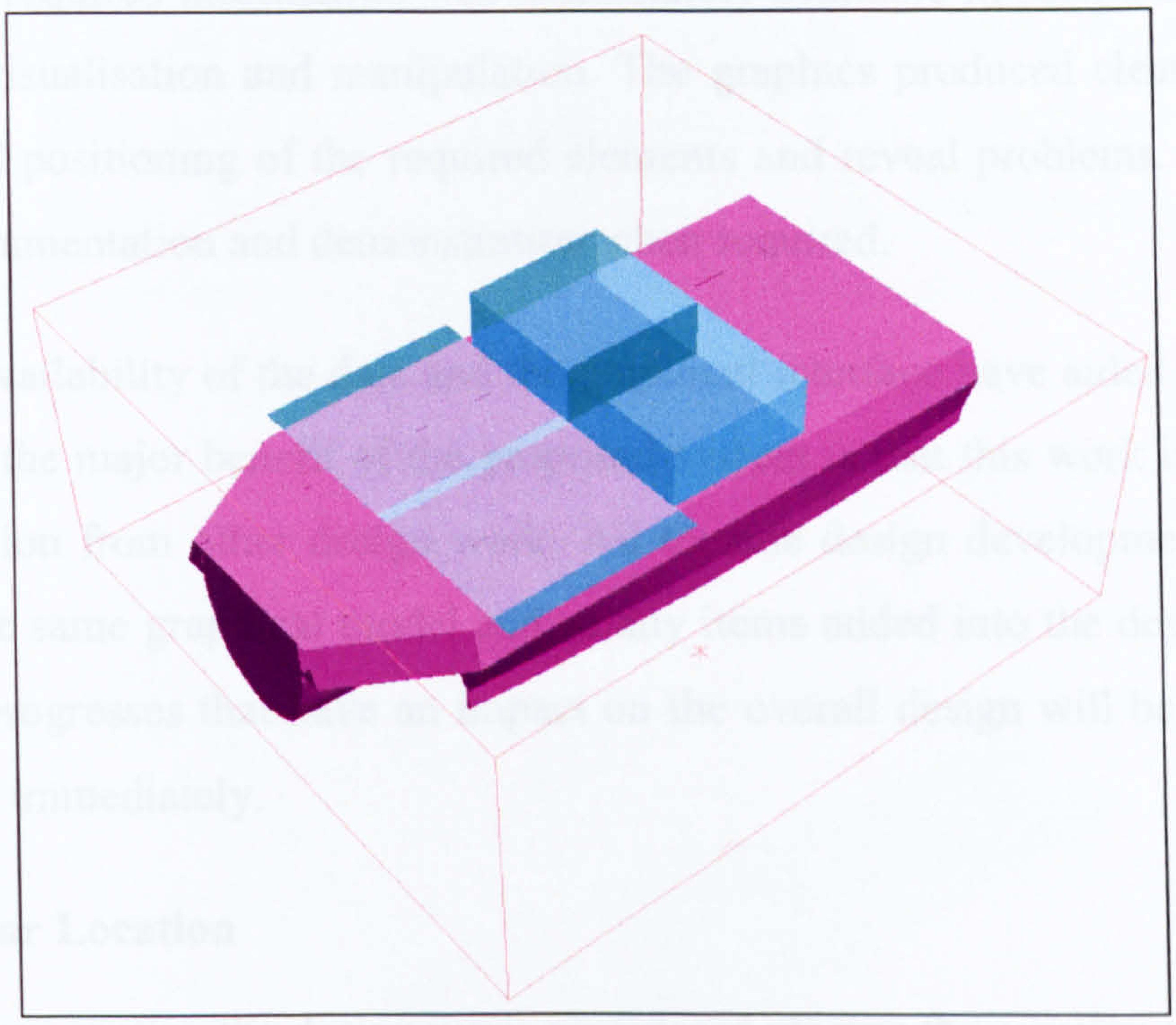


Figure 11.11 : Additional Space Required for Large Aircraft Hangar and Flightdeck

The knowledge gained from this investigation can be used to progress the overall design. There would be a number of options available, including modifying the beam, investigating longitudinal arrangement, or use of only one flightdeck. The use of the graphical interface and further manipulation of the different topside elements will allow additional studies to be performed. The designer may also be able to question the aviation requirements as it is clear that those specified place large restrictions on the design.

This example has demonstrated the use of the database and the graphical manipulation available to the designer. The fact that the ship in question was a Trimaran has not required modification to the methodology, the nature of the task could equally have been performed for a SWATH or similar unconventional ship configurations. The 'open' nature of the system allows the investigation of many differing design solutions in a 3D space that is not constrained. A monohull form would most likely preclude consideration of transverse hangar and flightdeck arrangements, through lack of available beam, but the proposed topside design tool has no such limits. The task itself was not complex and could easily have been carried out by the designer using more traditional means. The benefit of the system was that the required information was immediately available in such a manner as to allow easy visualisation and manipulation. The graphics produced clearly illustrate the proposed positioning of the required elements and reveal problems. This allows for clear documentation and demonstration when required.

Whilst the availability of the data and the graphical interface have aided the designer in this task, the major benefit of the proposed system is that this work is not carried out in isolation from other design work. All topside design development is carried out using the same graphical model and so any items added into the design space as the design progresses that have an impact on the overall design will be indicated to the designer immediately.

11.3.2. Radar Location

In the previous section the design work considered placing the aviation elements on a Trimaran design as this is likely to be a large design driver. Having located these aviation facilities the design can progress and the benefits of the integrated system can be further illustrated.

When placing radar and sensor equipment on the topside of a warship, the designer knows that there may be interference problems. Any method that allows increased confidence in the viability of any proposed design would benefit the design process.

For the example being illustrated two main search radar systems are to be placed in the topside environment. The first of these is a large air and sea search radar used as the main target indication radar on the ship. The second is a dedicated air search radar. The traditional arrangement for these can be seen on the Type 42 destroyer, the main radar on the main mast above the bridge and the air search radar located aft on the hangar roof [Janes 01] (Appendix 3.1.1). Through availability of data and the proposed methodology the designer can investigate differing solutions, particularly applicable to the Trimaran and other novel forms with large beam.

Figure 11.12 shows the position of the two radars, shown as simple spheres, placed into the topside design previously discussed. The proposed topside design system is immediately able to provide guidance, the graphical representation of the radar is shown on top of a pole. This pole is a design guide, captured as part of the geometric description, that indicates the required height above the waterline for the specified performance. These guides have been used to decide on the vertical positions shown. The designer is not forced to place the radar at the indicated height, but the availability of the design guide means that if requirements are not met, the designer is informed.

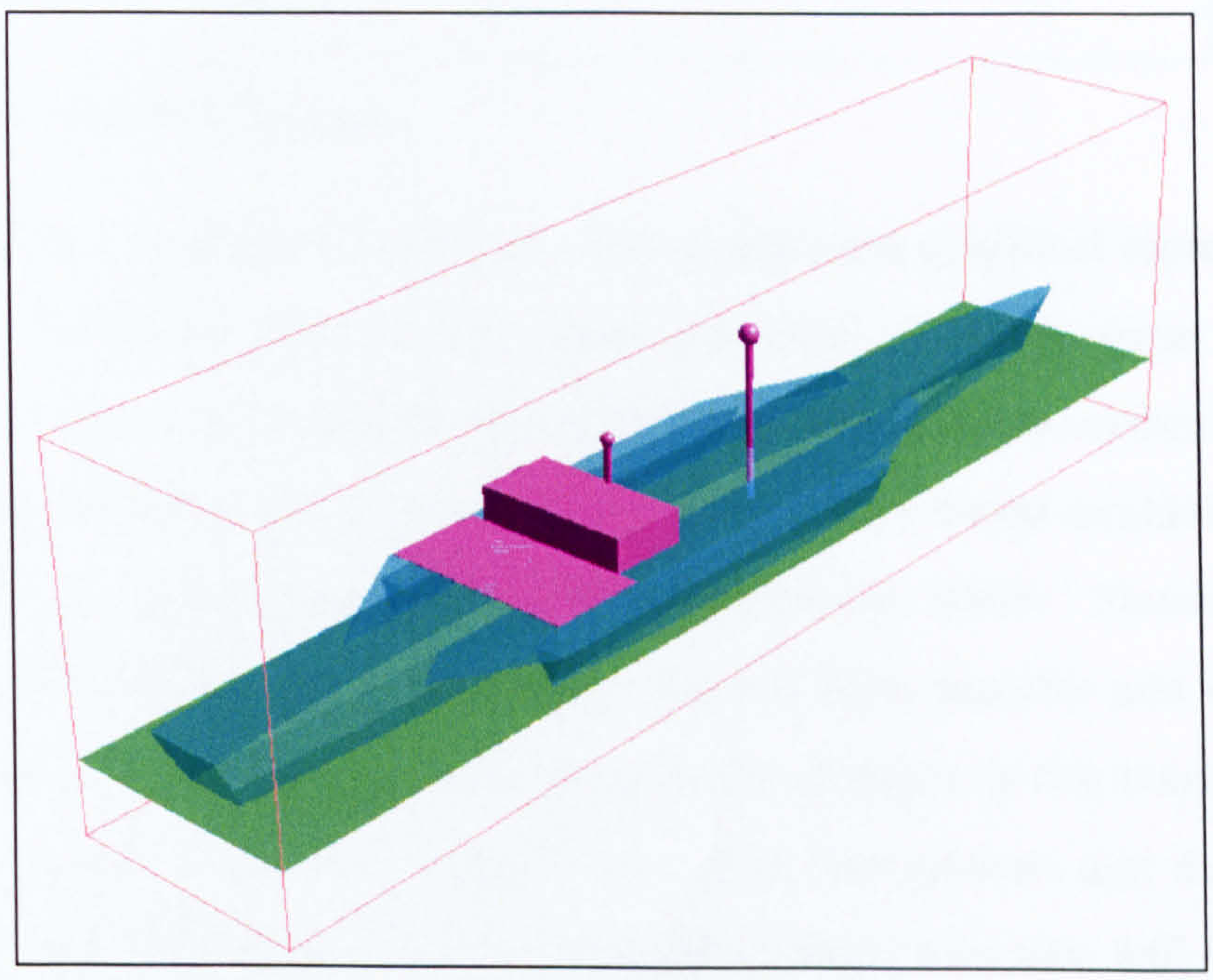


Figure 11.12 : Placement of Radar Systems

Further guidance was available during the choice of the two systems, the full database description, in conjunction with the geometric representation, allows the designer to choose suitable systems. Once placed into the design space guidance is available to help avoid EMI/EMC problems. The system can report any conflicts identified through interrogation of the FSUC and the EMI source victim matrix (Section 5.3).

Once positioned, the proposed system allows further interrogation of the individual aspects of the two radars. Through the use of graphical overlays the additional information contained within the system can be interrogated. Of most relevance to the positioning of the radar systems will be the exclusion envelopes required around the equipment, to avoid interference and damage to other systems (Figure 11.13).

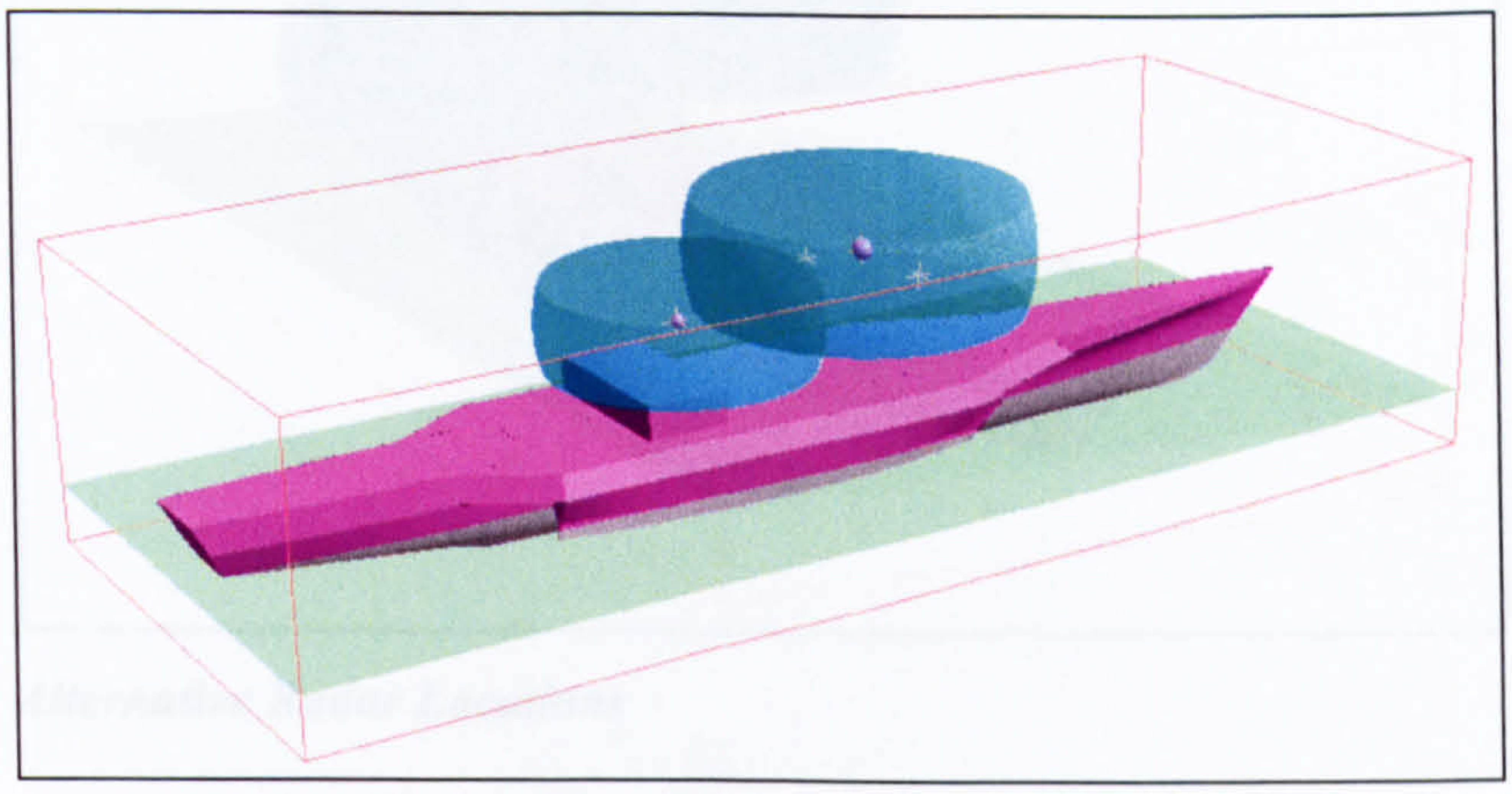


Figure 11.13 : Exclusion Envelopes

The figure above shows two additional semi-transparent graphical representations of the required exclusion zone for the equipment item, in reality these are not hard limits and actually need to capture the degradation of the system rather than giving a hard cut-off boundary. This requires a series of colour coded exclusion envelopes that indicate the ideal, acceptable and unacceptable limits. Simulation of this capability within AutoCAD or Paramarine has not been possible and would require bespoke programming. The indication given to the designer is that there are no major problems associated with the compatibility of the two systems and that it has been possible to place them at their required heights (further structure will be required to support them). In addition, the use of the exclusion envelope overlay has shown that neither seriously degrades the performance of the other.

The visualisation of the information, in this graphical manner, allows the designer to modify the design to investigate differing solutions. Figure 11.14 shows that through having a knowledge of the required separations alternative solutions can be shown, achievable through the use of the extra beam of the Trimaran. Here the two radar systems have been located transversely and the available guides used to ensure no major conflict occurs. Whilst this is not necessarily a better solution to that shown in

Figure 11.12 it demonstrates that the accessibility of the data held within the propsed system and the flexibility of the graphical interface allows for the easy investigation of design alternatives.

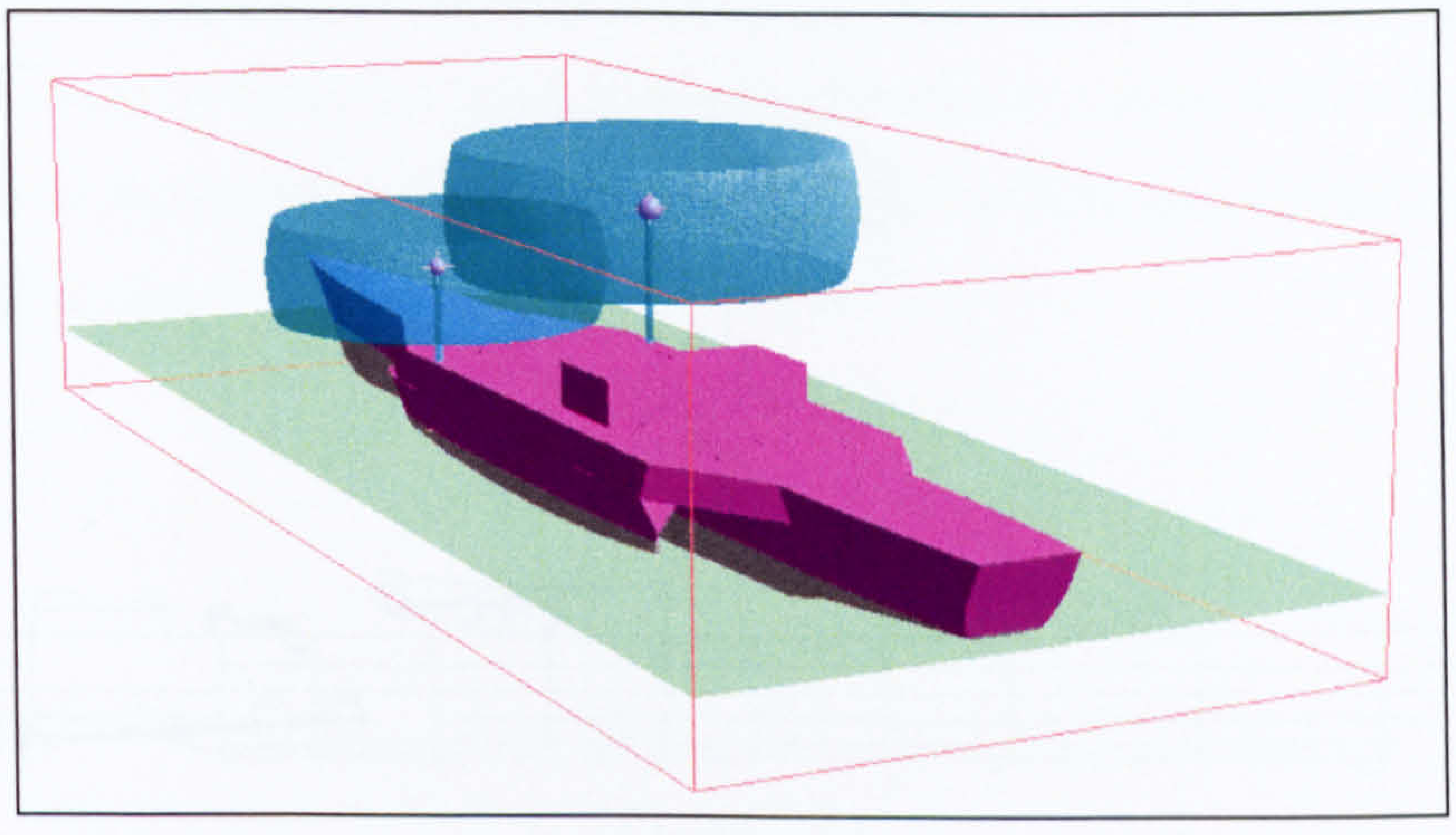


Figure 11.14 : Alternative Radar Locations

11.3.3. Trimaran Topside Design Studies

In order to investigate some of the layout problems encountered during a number of M.Sc. ship design exercises [Smith 96], [Alder 97] two topside designs were generated as part of the early phases of this research to highlight some of the issues associated with proposing a novel topside layout[143] [Bayliss 97]. Both of the designs illustrated have a single midship flight deck and a requirement for a minimum superstructure, resulting in a transverse mast arrangement.

An initial design, based on the ship design exercise for the UCL M.Sc. in Naval Architecture by Smith [Smith 96], is shown in Figure 11.15. The problems of excessive internal volume produced by Smith have been addressed in this investigation, to some degree, by reducing the size of the superstructure and locating it forward of the midship flightdeck. The small island of superstructure aft of the flight deck contains intakes and exhausts for an aft mounted gas turbine. The forward superstructure block contains a twin hangar arrangements and two transversely

[143] Neither of the layouts presented is intended to be a complete topside design, they were developed to provoke thought and discussion on why the proposed topside arrangement may not be possible. Although based on the design by Smith [Smith 96], during the development of the alternative topside arrangement no rebalancing of the overall ship design was carried out. As a result these figures are diagrammatic and do not necessarily represent a fully balanced ship design solution.

mounted masts to support the required radar systems. There is a forward mounted gun and trainable missile launcher. The boats have been located at the aft end of the flightdeck, launching next to the centre hull, behind the box structure.

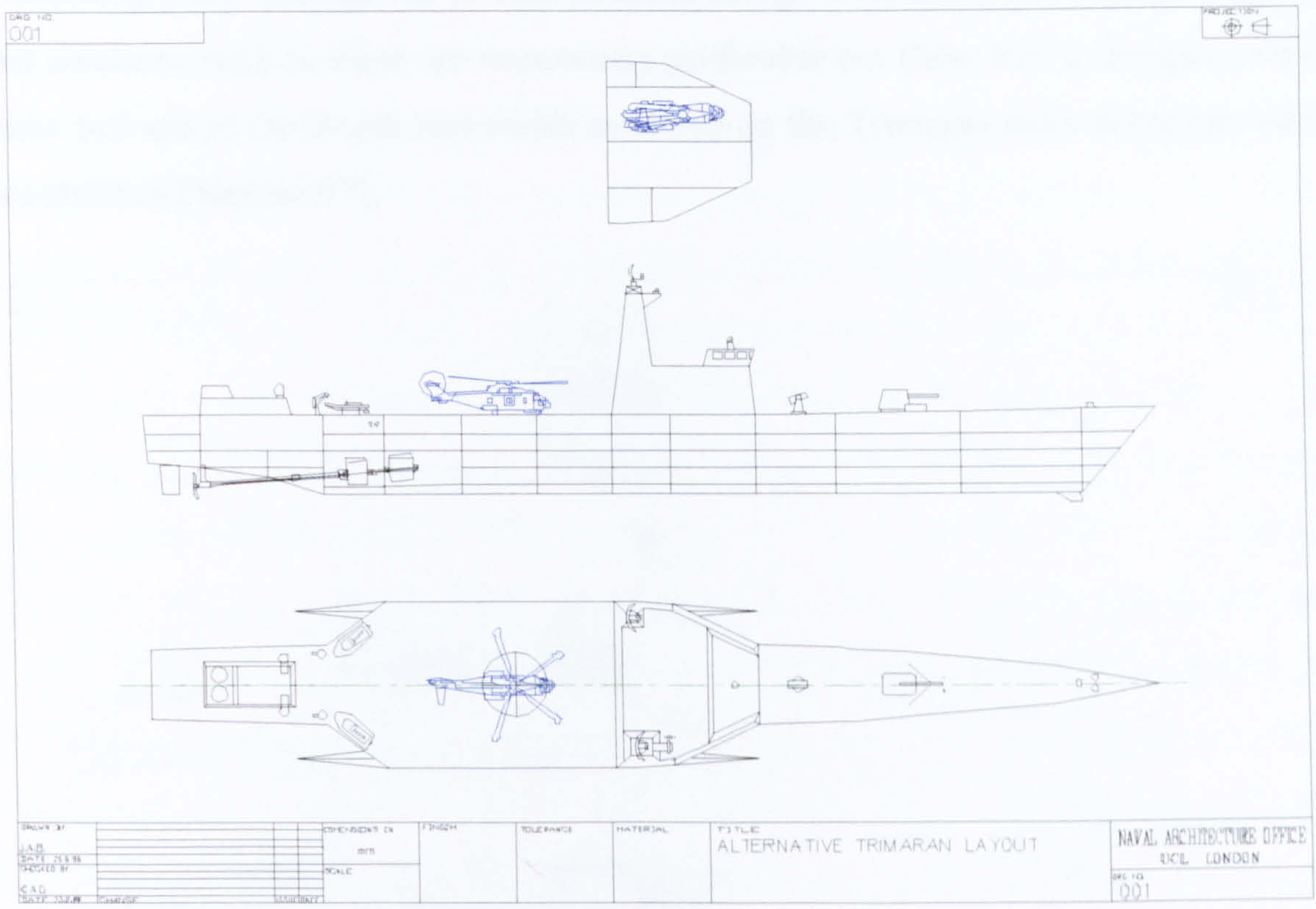


Figure 11.15 : Alternative Trimaran Layout [Bayliss 97]

A number of possible layout problems were noted:-

- Bridge is located very high, although visibility may be good the location may lead to excessive ship motion.
- Helicopter hangar arrangement could prove difficult for structural design, internal access to the superstructure and main hull and systems routing.
- Access to forward upper deck would be difficult.
- Masts are not far enough apart for communication antennae.
- SATCOM is very low on the after structure.
- Gas turbine space aft causes a large structural discontinuity.
- Arrangement of the sea boats is bad for helicopter operations and for launching and recovery of the boats. They are also vulnerable to green seas.

A further design took this process of minimum superstructure further and included a wave piercing bow and enclosed boats (Figure 11.16). This design was intended to provoke more radical design options in the UCL M.Sc. ship design exercise by illustrating some alternatives to conventional design solutions. This is not to suggest that solutions such as these are necessarily preferable but show how a designer could make full use of the length and width available on the Trimaran form to explore such possibilities [Bayliss 97].

[redacted]

Figure 11.16 : Further Alternative Trimaran Layout [Bayliss 97]

Both Figure 11.15 and Figure 11.16 illustrate the type of topside arrangement that the proposed methodology and design tools are intended to facilitate and assess. Sections 11.3.1 and 11.3.2 demonstrate how the use of the proposed topside design tool will enable some of the major topside design decisions to be made with more confidence.

Of the points listed above, detailing possible shortcomings in the topside arrangement, the functionality contained within the proposed tool will enable assessment to be made as to the viability of the arrangement. The use of the database of equipment with associated requirements would aid in locating all such items. The required height of the bridge would be better determined through the choice of appropriate superstructure blocks and their associated representative deck heights. Section 11.3.1 has demonstrated how details of viable aviation arrangements, held within the system database, can be used to ensure that the resulting design has suitable hangar and flightdeck layout. The structural arrangement is not solely a topside issue and interaction with whatever internal design system is being used, such as SURFCON, would allow the structural continuity to be checked. The requirement for access to the forward upper deck requires the use of access exclusion envelopes (Section 10.2.3) to be placed into the topside design to ensure suitable access is maintained and that this access requirement is passed into the internal arrangement system. Section 11.3.2 has demonstrated how the system can be used to assess the location of the radar and details of further communication systems enables their inclusion in the design. When this is done it will be clear whether is it possible to achieve the placement of long communication antennae between the masts (see Figure 11.7), or whether other solutions may need to be investigated. Similarly for the SATCOM arrangement, design guidance will be provided by the system on ideal height and the exclusion envelope will indicate if there is a problem with the SATCOM being this low and aft of the flightdeck. The use of the BAM will clearly show the obtained coverage. The structural discontinuity introduced by the gas turbine located aft will feed into the internal hull design but use of the exhaust definitions within the system will allow the applicability of the small island of aft superstructure to be assessed in terms of available volume for both the exhaust and associated signature control measures. The location of the sea boats, aft of the flightdeck on the first design (Figure 11.15) and internal to the superstructure in the second (Figure 11.16), can be assessed though use of operational envelope overlays but would require further discussion on the operability aspects.

Through the use of checklists, generated at the outset (Section 4.2.3), the current design could be assessed against the necessary requirements. This would highlight a number of topside equipment items that had not been considered, such as lifesaving devices and RAS arrangements, that would require consideration before a final concept design solution was reached. In addition to the tools detailed, the designer would have access to the full functionality of the proposed topside design tool throughout the concept design process. This means that all the other available design tools can be used, when required by the designer, to assess the design as it progresses. In this way, not only can the implications of a more novel topside layout be investigated, other aspects can also be considered.

11.4. Conclusion

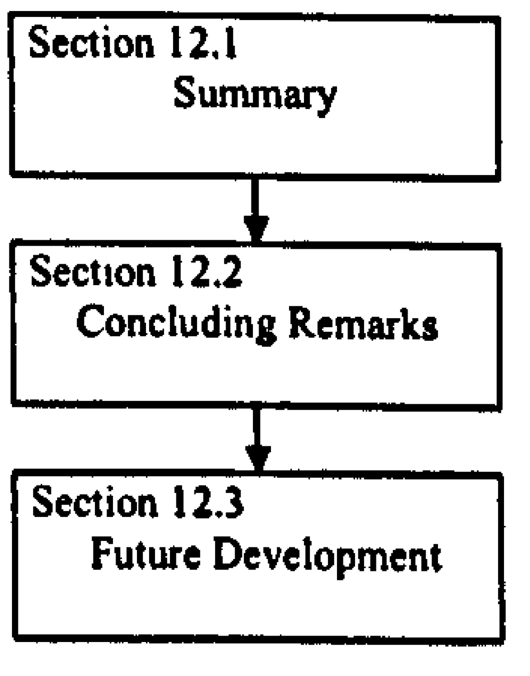
Whilst it has not been possible to fully simulate the design process[144], through the use of the breadboard system developed to allow research into the feasibility of the methodology, this chapter has shown how, during a concept design, the designer can be aided through access to the proposed tools and analysis techniques. There is no prescribed design process and the investigations shown in this chapter demonstrate that the methodology does not enforce a rigid design framework in which any design work has to be carried out. The proposed system allows the designer to evolve the design solutions, providing, when required, suitable tools and analyses. Through the availability of design guidance and tools, the designer is aided in the design task and this can provide greater confidence in the emerging design solution. Whilst the designer may not be an expert in all fields, the tool demonstrated here, if properly used[145], will allow design decisions to be made with greater confidence. By doing this there is a high probability that the final design solution will not contain any major aspects that would require significant rework due to emergent design flaws.

The design of any warship topside based around any typical novel hullform can be assessed in the same way that a monohull design can. The proposed methodology does not restrict designers in how they wish to explore the layout; indeed, the availability of the graphical representation and the associated design guidance will allow more novel design solutions to be investigated, whilst remaining within the bounds of a feasible design solution.

[144] Due to limitations of the breadboard system developed during the course of this research, not all of the proposed functionality has been simulated.

[145] The proposed topside design system, and the tools contained within it, do not result in a system than can be used by anyone. There is still a requirement for the designer to be experienced in naval architecture and to understand the limitations of the design framework in which any design work is carried out. The proposed tool will provide guidance and allow more detailed analysis than was previously available, but will not carry out the design work. At all times it is the designer who is evolving the design solution, the proposed methodology aids them in their task.

12. CONCLUSIONS



12.1. Summary

The aim of this thesis has been to propose a design methodology applicable to all forms of surface naval vessel, that provides, for the preliminary design stages, an improved capability to that currently available to the naval architect when designing the warship topside environment. The development of a warship design is a complex process involving many engineering disciplines. The preliminary design task is often undertaken by a single naval architect who is given the task to develop a number of different ship options to enable decision making before proceeding into further development. The provision of the suite of design tools proposed to aid the designer in this task will give greater confidence in the designs produced and allow for enhanced design documentation and control.

Available ship design methodologies have been discussed in Chapter 2, where the design problems associated with overall warship design are outlined. The majority of the available design tools concentrate on the development of the hullform and the internal arrangements rather than the topside arrangement (Sections 2.2 and 2.3). The development of the Building Block Methodology [Dicks 00] and SURFCON [Dicks 98], [Andrews 01], [Andrews & Pawling 03], [GRC 03] aims to address the design of the hull and internals in a spatial way. The research into an improved topside design methodology was carried out in conjunction with the Building Block (SURFCON) research work carried out by Dicks as part of the Naval Architecture Research Group at UCL. The two proposed tools are envisaged to operate together to provide a total warship design tool for use at the early stages of design [Bayliss 97], [Andrews & Bayliss 98]. The specific aspect of topside design and integration requirement is one for which fewer methodologies exist during preliminary design (Section 2.4). The nature of the topside environment is such that whilst there are a number of complex analysis tools used by specific engineering disciplines, there is a lack of a single methodology that cohesively addresses all of the topside design issues. It is this shortfall that this research work has addressed.

The underlying concepts behind the proposed topside design tool have been discussed (Chapter 3) and the requirements of the applicable tools detailed (Chapter

4), providing an initial framework for design tool development. This framework consists of a graphical interface, through which the majority of design interaction is undertaken, with a database containing the majority of the required additional information. These two aspects are supplemented, where necessary, by knowledge based systems and stand-alone analysis programs.

For the topside design areas that were considered of major importance (EMC, stealth and scenario modelling), it has been possible to develop design tools that will aid designers without them having to have specialist knowledge in all areas. The detailed models used to predict electromagnetic compatibility and interference demand too much design definition to be applicable during the early stages of design but major incompatibilities can be avoided through the use of simple design guidance such as the Frequency Spectrum Utilisation Chart (FSUC) and the source victim matrix (Section 5.3). Further guidance can be given on antennae requirements and location through capturing the graphical description and associated design rules within the design system (Section 5.4). For stealth, RCS and IR a combination of different techniques can be used ensure these factors are considered during preliminary design development (Chapter 6). Detailed investigations into the prediction of RCS has shown that the absolute values are not important, at the early design stages, but guidance to avoid possible problem areas is. This guidance can be provided without the need to actually calculate absolute levels of RCS (Section 6.5). Scenario modelling has been developed to aid the designer in choice and location of weapon systems (Chapter 7). This facility allows a quantitative investigation of different weapon choices and associated arrangements to be undertaken. This greatly enhances the credibility of emerging design solutions and helps to ensure that cost effective solutions are adopted.

The development of methodologies to aid the designer in these particular areas has demonstrated that the proposed methodology framework can encompass tools of the type required to address these differing aspects. This has allowed the features of the proposed topside design tool to be detailed (Chapter 8) and the data storage requirement to be detailed (Chapter 9). The framework developed has allowed further detailed topside ship guidance to be provided for use by the designer (Chapter

10). The individual tools in the proposed topside design system were demonstrated, as their development progressed, in the earlier chapters of the thesis while their use, within an overall integrated topside design tool, has been demonstrated for indicative monohull and trimaran combatant vessels in Chapter 11.

12.2. Concluding Remarks

The task of topside design and integration has been shown to be complex and diverse (Chapter 2), with requirements ranging from those simple to picture, such as access required for maintenance, to those where specialist knowledge is required, such as EMC and RCS. This research has shown that a number of specialist tools and techniques exist, but has also shown that these are not readily applicable to the early stages of warship design where little detailed design definition is likely to be available (Section 2.4). Furthermore the analysis these tools and techniques address often needs to be undertaken and assessed by a specialist in each of the particular fields to gain full understanding of the many implications. In the course of this research a number of tools have been identified that are applicable to the warship design process in the earliest stages. These tools, in contrast, are felt to be simple enough to be used by a non-specialist ship designer while still providing useful preliminary ship design guidance.

In order to provide the naval architect with a tool that will provide design guidance for topside integration at the early stages of design, a framework has been developed, that allows the coherent development and investigation of a warship design. The framework identified has a strong bias towards the use of graphics, as the topside integration problem is mainly a spatial one and visualisation is an important means to convey the multi-faceted complexity of topside design. The research has shown that tools suitable for inclusion in any proposed topside integration tool can be encompassed within the proposed framework and that they will provide useful preliminary design applicable information to the designer. This framework, and the tools contained within it, allow the designer to fully interact rather than presenting the designer with a 'black box' based solution. The process of design is evolutionary and the designer must, at all times, have full control over all aspects of the design.

The proposed methodology provides a structure in which this warship design development can take place, it does not dictate design decisions. The 'open' nature of the proposed tool means that it can be applied to all types of surface naval vessel, both conventional and unconventional, as no limitations are placed on the design space being worked upon that would preclude this.

The topside design and integration tool proposed allows the designer to investigate different warship design aspects in a consistent way. As a user of the proposed tool, it is not necessary to be an expert in the many diverse topside design aspects to produce a design free from major elements that may cause significant integration problems when the design is progressed further. The use of the system provides a number of prompts and a large amount of design guidance available to the designer if there are areas of concern. Whilst the designer may not be an expert in any particular area, the data captured within the system will allow sensible decisions to be made and will highlight, early in the design process, any significant shortfalls.

12.3. Future Development

This research work has detailed a design methodology, and identified a framework, for a computer based topside design and integration tool for use by the warship designer in the early stages of design. The specific techniques required within the framework have been defined and the data requirements identified. A breadboard system has been used throughout the research with the aim to develop the methodology, and associated techniques, that could be used to create a useable design tool. In a similar fashion to the research work into the Building Block Methodology [Dicks 00], [Andrews 01], the findings of this research need to be implemented by a software developer to create a toolset useable by the preliminary ship design team [Andrews & Pawling 03], [GRC 03].

It is recommended that any development be undertaken in parallel with the continuing development of the SURFCON system by GRC Limited and the Design Research Group at UCL [Andrews 01], [Andrews & Pawling 03], [GRC 03]. From the outset of this research the two tools (Building Block Methodology and topside integration tool) have been developed in conjunction with each other. In order to create an integrated warship design tool for use in the early stages of design there must be links between the design of the ship hull/internals and the topside arrangement [Andrews & Bayliss 97], [Bayliss 97], [Dicks 00]. The SURFCON development has now been incorporated as a module of the commercially available Paramarine suite of programs [Paramarine 02], [GRC 03] which already uses a graphical interface and a 3D solid model. The development of the proposed topside design and integration tool as part of the same suite of programs would ensure compatibility of data and ease any required data exchange.

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APPENDICES

APPENDIX 1

1. NUMERICAL WARSHIP DESIGN PROCESS

1.1. Introduction

This appendix briefly illustrates a simplified numerical sizing process used to design a warship to a given requirement [UCL 94], [UCL 99][146]. This is a simplified process and includes many assumptions that could not be made for a real design. This procedure has been used to run ship design exercises at UCL and many choices have been 'hard wired' to save time. A full design procedure would be far more complex but would follow the same steps. For each step full analysis would be undertaken obtaining details of real equipment or using algorithms based on earlier designs [UCL 97] rather than this simplified approach. A further example of this more complex sizing procedure can be seen the UK MOD CONDES computer code [Hyde & Andrews 92].

This process is shown within the context of this thesis to allow the unfamiliar reader to gain understanding of how this numerical process works. The numerical process requires no input about layout and configuration in order to reach a balanced design solution. When this process is used the designer will make decisions based upon separate layout studies but as these do not feed directly into the numerical sizing process, their influence on the design has to be carefully controlled and manually monitored by the designer.

1.2. Initial Sizing

1.2.1. Payload Analysis

Before an estimate of ship dimensions can be undertaken it is essential to know the payload of the design i.e. which weapons, sensors and communications facilities are to be installed.

[146] The procedure presented here is taken from the UCL numerical ship design procedure used by the B.Eng. Naval Architecture course [UCL 94]. This has been reviewed and revised to allow application to short courses [UCL 99].

For each item of payload the following requirements are needed:-

- Weight
- Volume
- Deck area
- Electrical power requirements
- Chilled water supply requirements
- Cost

The summation of weight and volume is categorised into groups using the UCL weight grouping scheme shown in Table A1.1.

Group	Description
1	Structure
2	Complement and associated requirements
3	Ship Services
4	Propulsion
5	Electrical Systems
6	Payload
7	Stores

Table A1.1 : UCL Weight Groups [UCL 97]

1.2.2. Sizing Process

The sizing procedure is shown in Figure A1.1, requiring the design to be balanced iteratively in terms of weight and space. From the value of payload volume an initial assessment of total enclosed volume is made for the first iteration by using a default payload volume fraction (p.v.f.). Displacement is estimated for the first iteration using a default overall density (ρ). Volume (V), displacement (Δ) and linear dimensions are calculated for a given set of form parameters. In conjunction with specified operational parameters, group values for weight and space can be calculated using algorithms derived from previous designs. The summation of these groups must be compared to the initial assumed total values. If the design is not balanced the aggregate of group values for volume and weight replace the initial values and a subsequent iteration conducted. This process is repeated until an acceptable balance is achieved.

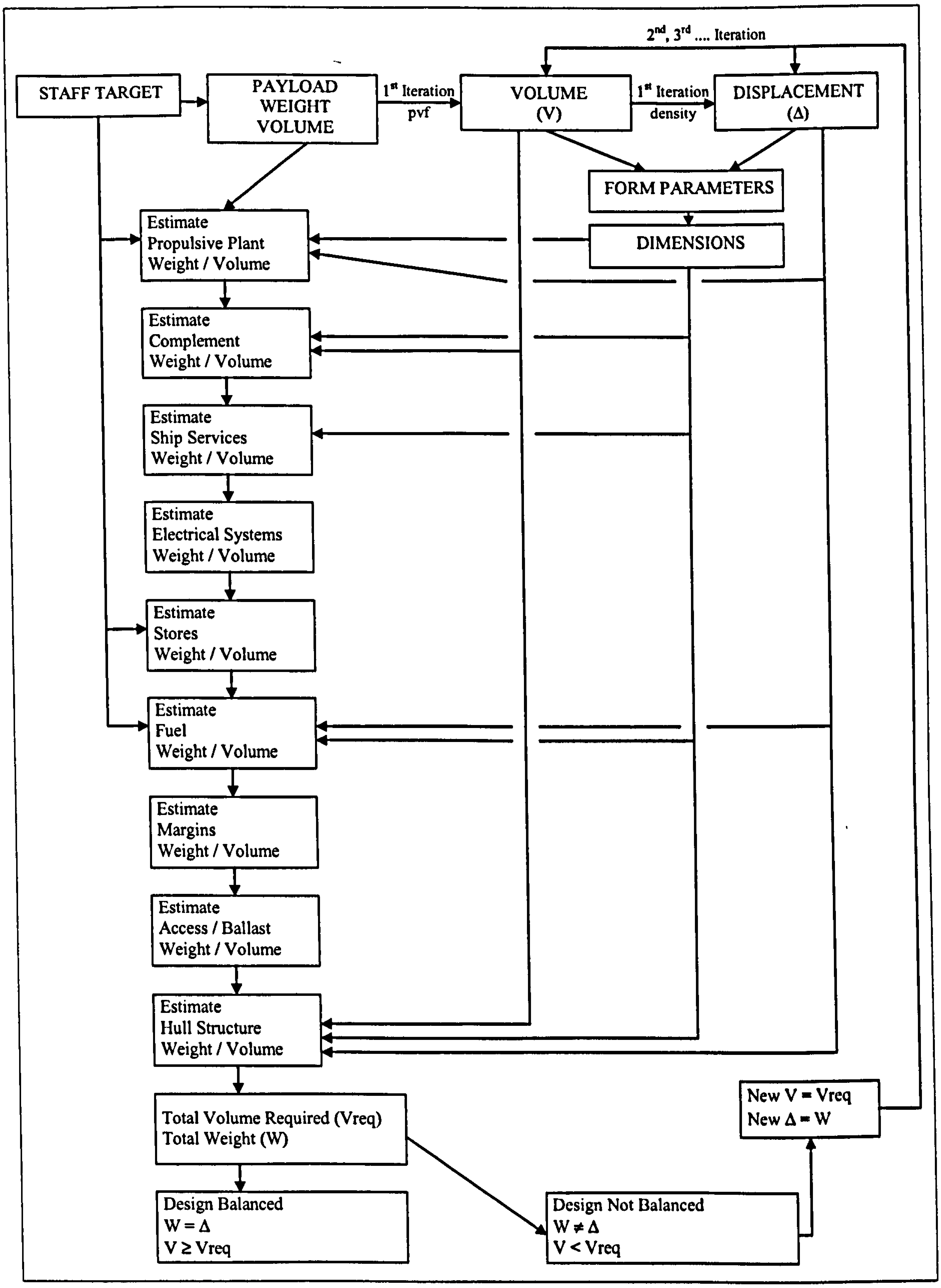

Figure A1.1 : Numerical Warship Synthesis Procedure [UCL 99]

In order for the design to be viable the displacement has to equal the weight of the groups and the volume available in the hull and superstructure has to be larger than that required by the groups.

weight	=	displacement
volume available	≥	volume required

1.3. Sizing Procedure

1.3.1. Payload Estimation

Step 1 : Payload Data

Before sizing can proceed, values for the following items need to be selected:-

1. Weapon and sensor payload
2. Machinery fit and range

The weapon and sensor payload is dictated by the role of the ship. There may be a variety of choices available for machinery and the numerical process does allow for fast calculation of different options. Additionally a deck head height is required for some volume calculations.

1.3.2. Dimension Calculations

Step 2 : Initial Estimation of Volume

Payload Volume

$$V = \frac{pv}{p.v.f}$$

Payload Volume Fraction (for frigate p.v.f ≈ 0.2)

Step 3 : Initial Displacement Estimation

$$\Delta = \rho V$$

Overall Density (for frigate $\rho \approx 0.3$ tonne/m^3)

Step 4 : Volume of Displacement

$$\nabla = \left(\frac{\Delta}{\rho_W}\right)$$

Density of Seawater ($1025.2kg/m^3$)

Step 5 : Immersed Hull Dimensions

As $\nabla = LBTC_B$ (C_B = Block Coefficient), Length (L), Draught (T) and Beam (B) can be calculated.

$$L = M\nabla^{1/3}$$

$$T = \nabla^{1/3}/[M\ k_B\ C_B]^{1/2}$$

$$B = k_B.T$$

Where $M = L/\nabla^{1/3}$ (for frigates $\approx$ 7.50)

$k_B = B/T$ (for frigates $\approx$ 3.25)

$C_B = C_p \cdot C_m$ (for frigates $\approx$ 0.50)

Prismatic Coefficient (C_p) Midships Coefficient (C_m)

Step 6 : Determination of Main Hull Volume

Total volume of ship (V) is given by

$$V = V_m + V_s$$

Main Hull Volume (V_m) Superstructure Volume (V_s)

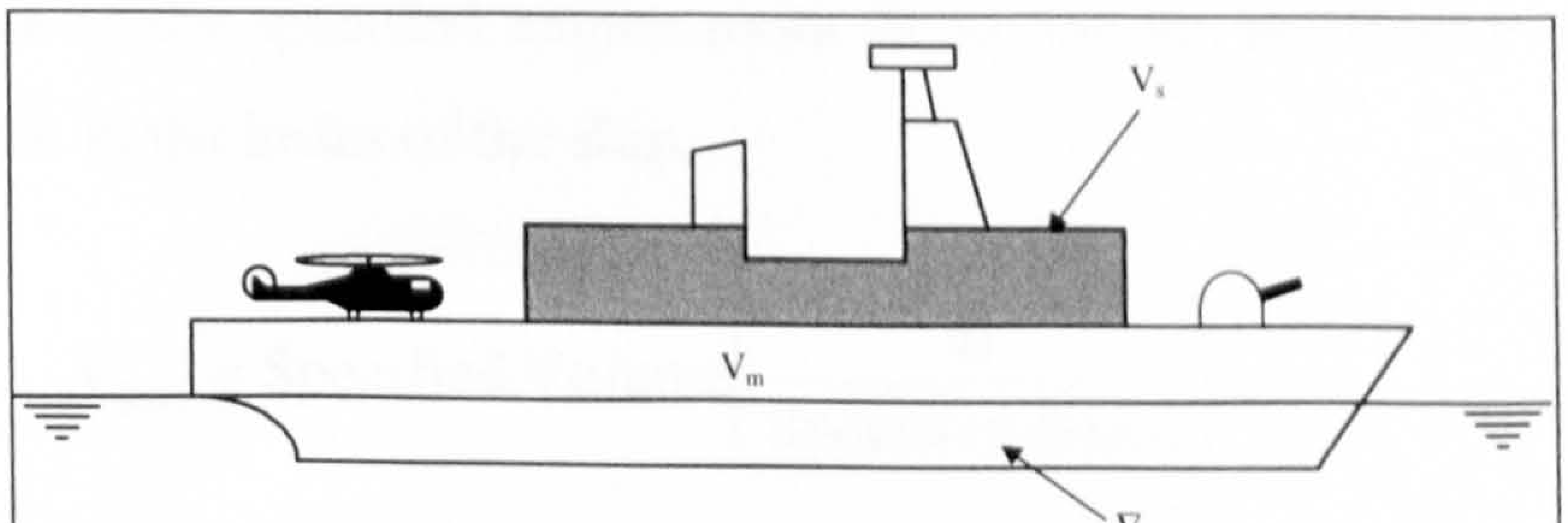

Figure A1.2 : Main Hull and Superstructure Volume [UCL 99]

Main Hull Volume (V_m) is given by:-

$$V_m = V - V_s \text{ or } V_m = V(1 - v_s) \qquad \text{where } v_s = \frac{V_s}{V}$$

Superstructure Proportion (for frigates $v_s \approx 0.225$)

Step 7 : Main Hull Displacement Proportion

Main Hull Displacement Proportion (ρ_m) is defined as: $\rho_m = \dfrac{\nabla}{V_m}$

Step 8 : Main Hull Depth

Depth (D) of main hull (for a wall sided ship) is given by:-

$$D = \left[\frac{C_B}{C_W}\left[\cdot\frac{1}{\rho_m} - 1\right] + 1\right]T$$

For initial sizing assume Waterplane Coefficient (C_w) $\approx$ 0.75

Note: $Cw \approx \dfrac{2C_p}{1+C_p} \quad (\therefore C_p \approx 0.6)$

1.3.3. Group Calculations

Step 9 : Propulsive Plant (Group 4)

Select a value for the propulsive plant weight and volume W_{grp4} and V_{grp4}. This should be appropriate to the machinery fit specified in the requirements. The weight of Group 4 will remain constant (in this simple procedure) but it is necessary to scale up the volume of the specified engine room fit so that the machinery room fills the space available in the beam of the ship.

$$V_{grp4} = \text{Specified Volume}\left(\frac{B}{\text{Specified Beam}}\right)$$

Step 10 : Estimation of Complement

Figure A1.3 provides a method to estimate the complement for a warship based on 1980's UK Type 23 Frigate manning philosophy. This graph does not include margins, air crew or personnel for out of area operations.

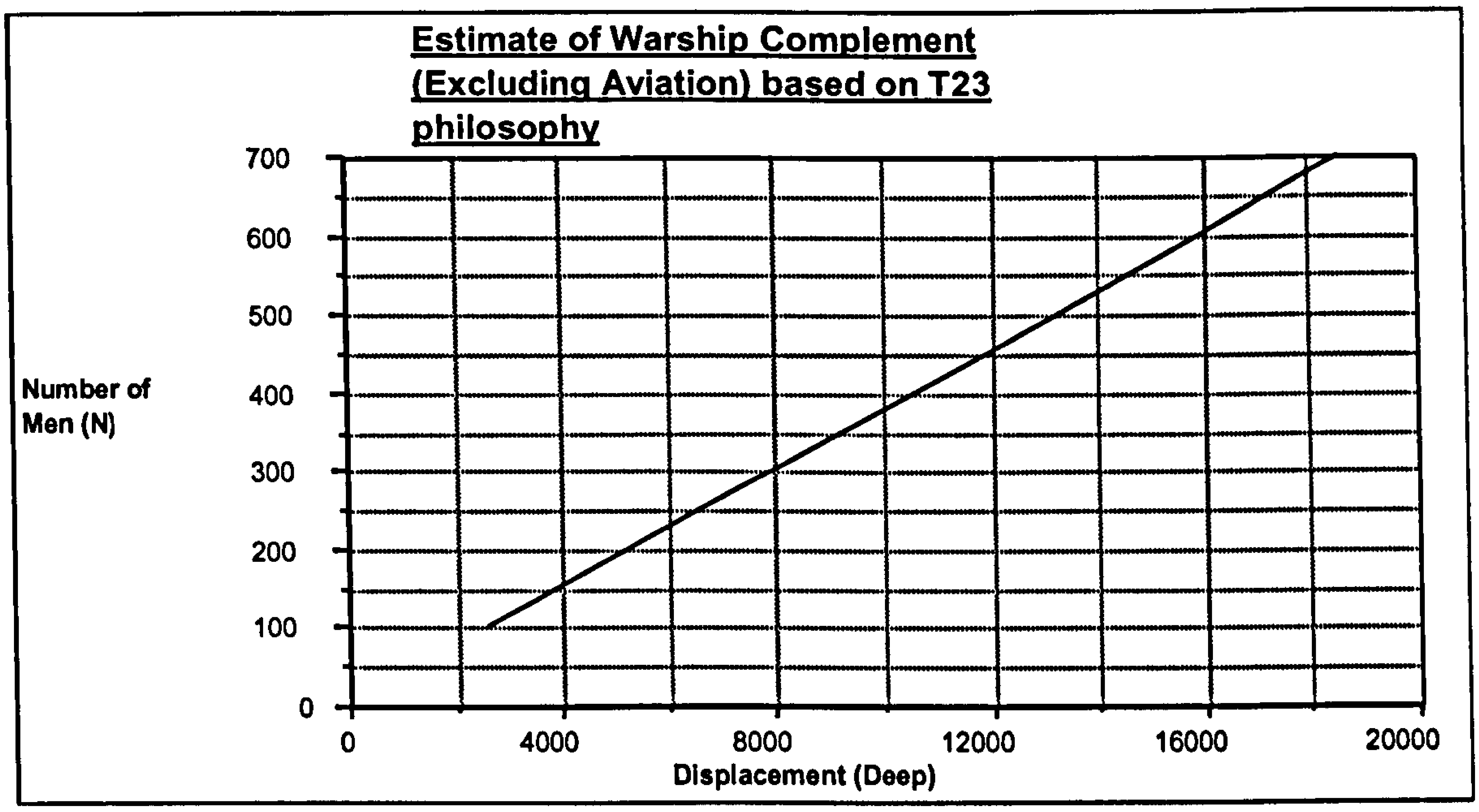

Figure A1.3 : Estimation of Warship Complement [UCL 99]

This graph is of the form : $N = \dfrac{\Delta}{26.2}$

The following margins must be added to the complement figure estimated above:-

6% for training and advancement.

10% board margin for subsequent enhancements.

The personnel necessary to operate any aircraft specified.

Step 11 : Complement Breakdown

A broad indication of the complement breakdown is shown in Table A1.2.

Officers (Y)	0.075N
CPO's (C)	0.11N
PO's (P)	0.14N
JR's (J)	0.675N

Table A1.2 : Warship Complement Breakdown [UCL 99]

Step 12 : Complement Weight and Space (Group 2)

The following formulae can be used to estimate the space and weight demands by complement where R is the total number of ratings and S is the number of days of stores required. Deck head height (h_d) is used to convert some area formulae to volume requirements.

Weight of Group 2

$$W_{grp2} = 2.82 + 1.224Y + 0.368C + 0.35P + 0.333J + 0.258N + \ldots.$$

$$\ldots.\ 0.47\text{x}10^{-3}RS + 3.84\text{x}10^{-3}NS$$

Volume of Group 2

$$V_{grp2} = h_d \text{ x } (17.8 + 8.16Y + 4.0C + 3.6P + 3.14J) + 5.1 + 0.75Y + \ldots.$$

$$\ldots.\ 0.05J + 0.019R + 0.001RS + 0.00605NS + 0.559N$$

Step 13 : Liquid Stores Weight and Volume

Liquids carried other than fuel (Table A1.3).

	Weight (Tonnes)	Volume (m^3)
Lub oil	5	6
AVCAT	30	36
Fresh water stowage	70	70
Total	105	112

Table A1.3 : Liquids Carried other than Fuel [UCL 99]

$$W_{liqu7} = 105 \text{ te}$$
$$V_{liqu7} = 112 \text{ m}^3$$

Step 14 : Solid Stores Weight and Volume

Volume of solid stores : $V_{solid7} = 0 \text{ m}^3$

The volume of stores is included later in the volume of store rooms (Step 22).

Weight of solid stores : $W_{solid7} = 34.0 \text{ te}$

These are divided between the following items in the following proportions shown in Table A1.4.

Dry provisions	11%
Frozen provisions	6%
Fresh provisions	15%
Clothing and mess gear	6%
NAAFI: Canteen and messing stores	12%
Tinned beer	12%
Naval stores	38%

Table A1.4 : Breakdown of Stores [UCL 99]

Step 15 : Fuel Stores Weight and Volume

This can be estimated from the specific fuel consumption curves and stated endurance on the cruise engines. This needs to be done for the two cruise engines and two of the four diesel generators (Figure A1.4). For the purposes of this exercise the number and type of engines are predetermined.

Allowances should be made during the preliminary design stages for fuel capacity to be increased in order to compensate for:-

(i) lack of pumpability.
(ii) tanks not being pressed fully.
(iii) the volume in a tank taken up by structure.

A factor of 0.95 is suitable in each case.

Specific volume of fuel is 1.19m^3/tonne.

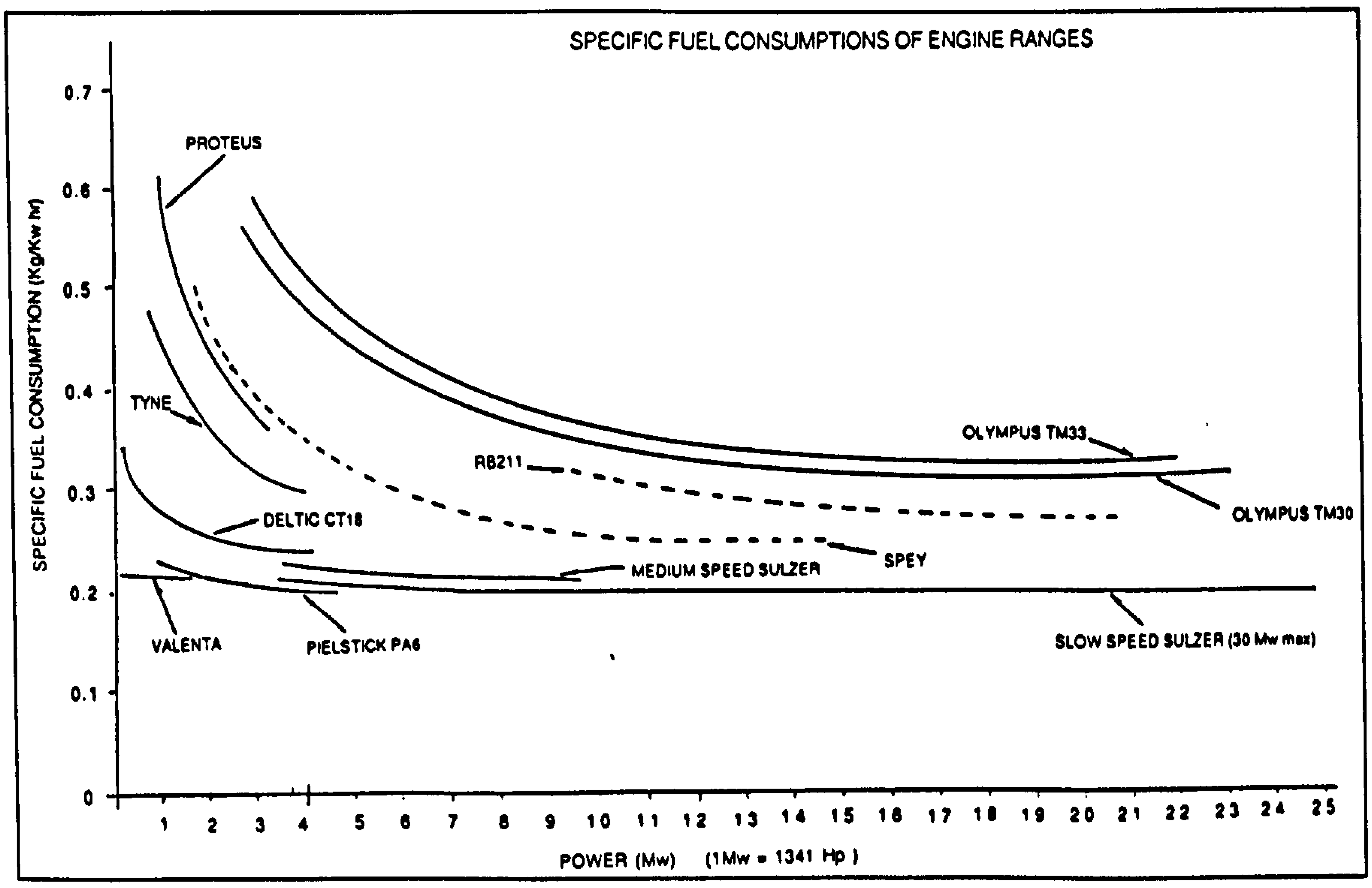

Figure A1.4 : Specific Fuel Consumption Curves [UCL 99]

Step 16 : Total Stores Weight and Volume (Group 7)

$$W_{grp7} = W_{liqu7} + W_{fuel7} + W_{solid7}$$

$$V_{grp7} = V_{liqu7} + V_{fuel7} + V_{solid7}$$

Step 17 : Electrical Auxiliary Weight and Volume

For a new design of ship an electrical load chart has to be prepared, based on the best available known features of the design. It is important that the load chart be compiled as early as possible in the design. Total load values thus obtained are used to determine the installed generating capacity and the size of generators, taking into account load growth. This provides values of V_{aux5} and W_{aux5}.

Step 18 : Calculation of Net Volume

For subsequent calculations the net volume (V_N) is required. This is defined as the total internal volume minus machinery and tanks. This can be represented by the following relationship:-

$$V_N = V - V_{fuel7} - V_{liqu7} - V_{grp4} - V_{aux5}$$

Step 19 : Electrical Remainder Weight and Volume

In addition to the diesel generator weights it is necessary to estimate the weight and space requirements associated with the switchboards and electrical distribution. The following formulae apply:-

Weight of remaining items in group 5 : $W_{rem5} = 33.0 + 8.76\text{x}10^{-3}V_N$

Volume of remaining items in group 5 : $V_{rem5} = (23 + 2\text{x}10^{-3}V_N)h_d$

Step 20 : Total Electrical Weight and Volume (Group 5)

$$W_{grp5} = W_{rem5} + W_{aux5}$$

$$V_{grp5} = V_{rem5} + V_{aux5}$$

Step 21 : Ship Services (Group 3)

$$W_{grp3} = 101.0 + 8.9x10^{-3}V_N + 0.26L + W_{cw}$$

$$V_{grp3} = h_d \text{ x } (20 + 5x10^{-3}V_N) + 62 + V_{cw}$$

It is necessary to estimate the chilled water requirements (W_{cw} and V_{cw}).

Step 22 : Hull Structure (Group 1)

Weight of structure : $W_{str} = 0.013L^{1.36}BD$

$$W_{grp1} = W_{str} + 142.0 + 5.13x10^{-3}V$$

$$V_{grp1} = h_d \text{ x } (170.0 + 4.17x10^{-2}V + 0.07V_N)$$

The above formulae account for all other hull structure other than that associated with the main strength of the ship, this includes access, ballast, deck fittings, anchors and rudders.

1.3.4. Total Ship Calculations

Step 23 : Group Totals

$$W = W_{grp1} + W_{grp2} + W_{grp3} + W_{grp4} + W_{grp5} + W_{grp6} + W_{grp7}$$

$$V_{req} = V_{grp1} + V_{grp2} + V_{grp3} + V_{grp4} + V_{grp5} + V_{grp6} + V_{grp7}$$

Where W is the total weight and V_{req} is the required volume.

Step 24 : Application of Margins

Table A1.5 indicates typical margins appropriate to the main groups of a warship design which does not markedly differ from its predecessors.

Main Group	Margin (%)	
	Weight	Space
1 Hull	5	0
2 Personnel	0	5
3 General Service	5	2
4 Machinery	4	0
5 Electrics	5	0
6 Payload	7	10
7 Variable	4	4

Table A1.5 : Typical Warship Margin Allowances [UCL 99]

In addition the following margins should be added:-

Board Margin allow 2% weight on 1 Deck amidships

Growth Margin allow 5% weight.

Step 25 : Total Displacement and Volume

Total displacement and volume can now be calculated from the group totals and the margins and compared to the initial input values. The design is balanced if:-

$$W = \Delta \qquad \text{and} \qquad V \geq V_{req}$$

Otherwise iterate with new values of W & V_{req} replacing the initial estimations until a balance is achieved.

APPENDIX 2

2. TYPICAL FRIGATE WEAPON AND SENSOR FIT [BROADBENT 96]

2.1. Weapon and Sensor Fit

1) Weapons and sensors
2) Bow sonar
3) Medium calibre gun
4) Anti missile / aircraft missile launcher
5) RF and IR rocket decoy launchers
6) Floating decoy launchers
7) Electro optical gun director
8) Forward missile tracker
9) Navigation radar
10) Electronic support measures
11) Manned target indication sights
12) ECM jammer
13) Main target surveillance and target indication radar and IFF
14) Small calibre guns
15) Additional sonars, echo sounders etc.
16) Semi rigid inflatable boats
17) Surface to surface guided missile system
18) Long range surveillance radar
19) CIWS guns
20) CIWS tracker
21) Anti submarine torpedo launching tubes
22) Helicopter landing lights and guidance radar
23) Helicopter
24) Towed sonar
25) Torpedo decoy
26) Communications antennae/equipment
27) International maritime VHF
28) International aviation UHF
29) Military VHF, several antennae and systems
30) Military UHF, several antennae and systems
31) VHF direction finding set

32) Emergency VHF
33) Global positioning system navigators receivers
34) Weather satellite receiver
35) Visual signalling lamps and flag signalling
36) I band satellite communication system
37) INMARSAT commercial satellite communication system
38) High frequency (HF) radio transmitters, several antennae and systems
39) HF receivers, several antennae and systems
40) Emergency HF transmitters and receivers
41) Medium frequency (MF) radio transmitter/receiver

2.2. Topside Design Checklist

• Arcs of fire	-	coverage
		channels of fire
		interaction with other projectiles
• Blockage	-	transmissions / reception arcs
• Access	-	installation and repair
		reload and operation
• Navigation	-	visibility
		reserve positions
		seamanship restrictions
• Stability	-	topside weight
		icing and windage
• Height	-	wire rigs
		versus operational effectiveness
• Separation	-	from other equipment, power / frequency
		from superstructures, antennae characteristics
• RADHAZ	-	personnel
		explosives fuel / replenishment at sea
		aviation

- RAS - routes
  positions
  special handling
- Cable lengths - control / firing lines
  data highway
  feeders
- Missile efflux - personnel
  equipment and structures
- Alignment - static and dynamic
  flexure
- Shock and vibration
- Position verses ship motion
- Funnel gases
- Green seas
- Radar cross section
- IR signature
- Laser safety
- Magazine location
- Damage control / NBCD
- Operational survivability
- Minimisation of manning
- Docking / berthing considerations
- Multipath effects
- Electromagnetic interference
- Aviation interactions (crash on deck, turbulence etc)
- Ground planes

Other areas requiring consideration in addition to this list by Broadbent include:-

- Boat handling
- Escape and rescue

APPENDIX 3

3. EXAMPLES OF WARSHIP TOPSIDE ARRANGEMENTS

3.1. Typical Current Designs

The following provides a brief introduction to different types of ship with discussion on relevant topside areas. Figures illustrate different design solutions meeting a variety of design requirements. Warships are generally more complex than commercial ships due to the requirement to carry a large amount of equipment to enable them to carry out a diverse variety of tasks. This equipment is specifically designed for, and operated on naval vessels.

Three of the current UK Royal Navy warships are discussed and are used to illustrate a variety of different features of topside design[147].

3.1.1. Type 42 Destroyer

The Type 42 Destroyer (Figure A3.1), (Figure A3.2) was first commissioned in 1976 and its topside environment is dominated by the requirement for air defence.

Image removed due to third party copyright

Figure A3.1 : Type 42 Destroyer [Janes 01]

Image removed due to third party copyright

Figure A3.2 : Type 42 Destroyer Schematic [Janes 01]

A large air search radar (10) is required along with two fire control radars, forward and aft (14), in order to control the Sea Dart missile system (1). The Sea Dart system

[147] The main source of information for this discussion has been Janes [Janes 01]. Other references are quoted in the text when relevant.

has a trainable launcher on the foredeck carrying two missiles at one time. Reload is automatic from the weapon storage below the launcher. This weapon system, consisting of the radar, trackers and launcher system can be seen to dominate a large area of the topside. The air search radar is placed forward of the other masts carrying additional sensors and radars (11), (12). This means that the performance of the air search radar over the arc of blockage astern is severely degraded, however this trade off was sensible due to the size of the radar and the requirements of the other sensors. To provide full coverage for the trackers the conventional arrangement is to place one forward and one aft as has been done. This provides full coverage and also large areas where double coverage is achieved. The missile launcher and 4.5″ gun (2) have been placed forward of the superstructure behind a small breakwater to avoid damage due to green seas[148]. The placement of this launcher and gun have major effects upon the internal layout due to the requirement for weapon handling and stowage directly below. The organic capability[149] provided for the helicopter (15) requires a large flight deck and hangar at the after end of the ship and has a major impact on the topside arrangement. The approach to the flight deck has to remain clear to enable the aircraft to land, and for a ship of this size, the hangar takes up nearly full width forward of the flight deck.

The remainder of the topside is taken up with the superstructure, containing the bridge, officers accommodation, radar offices and inlets and exhaust from the main engines. Exhaust and air inlet requirements for the engine rooms have a significant impact on the topside, modern gas turbines require large amount of air and hence large inlets and exhausts of minimum length. Also in the funnel are methods to reduce the heat of the exhaust gas to avoid infrared detection, these systems add to the size of the overall funnel. These systems can either be in the form of shielding, to avoid hot-spots being created, or more complex diffuser systems [Thompson et al. 99].

[148] Green seas occur when water breaks over the bow of the ship onto the foredeck.
[149] Organic capability - the provision of a suitable flight deck, helicopter handling system and hangar with access to refuelling and full maintenance facilities.

Although the major systems described can be seen to dominate the topside a large amount of additional equipment is required, these are further weapon systems, communications systems, lifesaving equipment, replenishment at sea (RAS) arrangements and ship handling equipment.

3.1.2. Type 23 Frigate

The Type 23 anti-submarine warfare frigate [Thomas & Easton 91] (Figure A3.3), (Figure A3.4) was first commissioned in 1989 and represents a later design than the Type 42 and the influence of the requirement for radar cross section reduction can be seen. The main superstructure is sloped to reduce radar cross section and an attempt has been made to reduce the topside clutter.

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Figure A3.3 : Type 23 Frigate [Janes 01]

Image removed due to third party copyright

Figure A3.4 : Type 23 Frigate Schematic [Janes 01]

The use of the vertical launch system (VLS) for the Seawolf missiles (2) results in a less cluttered layout which does not require the placement of trainable missile launchers, but this system penetrates through the weatherdeck and so the placement of this system interacts heavily with the internal layout. Radar trackers (12) are still required and can be seen on the forward and aft superstructure blocks in similar positions to that on the Type 42. The additional major weapon systems seen are the 4.5″ gun (3) and the Harpoon surface-to surface missiles (1). These Harpoon missile launchers face port and starboard and fire over the sides of the ship requiring these areas to be kept clear to avoid the missile efflux damaging systems or personnel when launching. The Type 23 is an anti-submarine warfare vessel, not an anti-air warfare vessel and so there is no requirement for an additional air search radar. Here a large main mast carries the main radar (10), electronic warfare sensors (7), navigation radar (9) and the satellite communication antennae (8). A second smaller mast aft of the funnel carries further sensors, providing separation, and allows for the large roof antennae to be strung between these masts [Gates 87].

The large funnel forms a central part of the superstructure. The position is dictated to a large extent by the location of the engine rooms within the hull. The requirement to provide an organic capability for the much larger Merlin helicopter (13) compared to the Lynx helicopter on the Type 42 dominates the layout of the after end of the ship.

3.1.3. Single Role Minehunter (SRMH)

The topside arrangement on smaller and cheaper vessels, such as the single role minehunter (Figure A3.5) is equally important in their design.

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Figure A3.5 : Single Role Mine Hunter [Janes 01]

These vessels were designed to detect and destroy mines, this is a very specific task and can be considered more specialised than the roles of the Type 42 and Type 23 Classes already discussed. The requirements for the SRMH are different from the destroyers and frigates in that a large amount of equipment handling is required. These vessels operate a remote control mine disposal system (RCMDS) that has to be stored and deployed from the ship. The after end of the ship is dominated by deck handling areas and the crane used to deploy the RCDMS is seen at the stern. This ship is far smaller than those previously discussed, 450 tonnes compared to over

4000 tonnes [Janes 01] and has far fewer systems, however the topside appears cluttered with a variety of equipment, ranging from the small gun on the foredeck structure, boats, safety equipment and sensors. Again the exhaust requirement impacts on the upper deck arrangement.

3.2. The Influence of Weapon Systems

The need for a new warship is identified through operational analysis and leads to a new operational requirement or the need to replace an existing class with an updated vessel. In order to fulfil this requirement new equipment is often associated with the new ship class. Due to the nature of a warship this new equipment is often either an improved or new weapon system which meets the operational requirement. This weapon system is often one of the main design drivers, and dictates the majority of topside arrangement decisions [Purvis 74], [Schaffer & Kloehn 91]. This is not always the case, in some instances the new requirement is not equipment based but ship performance based. An example of this type of design driver is the UK Castle Class patrol vessel, where the major driver was a requirement for improved seakeeping [Brown & Marshall 78].

An example of a weapon system dominating the ship design is seen in the US DDG51 Arleigh Burke Class guided missile destroyers (Figure A3.6), (Figure A3.7).

Figure A3.6 : DDG51 Arleigh Burke Class Guided Missile Destroyer [Janes 01]

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Figure A3.7 : DDG51 Arleigh Burke Class Guided Missile Destroyer Schematic [Janes 01]

The design is dominated by the four large SPY1 air search and fire control phased arrays placed onto the superstructure (8) which in combination with the vertical launch silo (2) located aft of the gun (3) on the foredeck provide the main weapon system. The superstructure has to provide support for these large arrays but also orientate the arrays into the correct positions. It is this requirement that has dictated the shape of this superstructure block. The resulting ship is far larger than the UK Type 23 and Type 42, 8300 tonnes compared to approximately 4000 tonnes [Janes 01]. The differences between the engineering design standards used in the ship design and construction account for some of this difference [Ferreiro & Stonehouse 93] but the majority is due to the influence of the weapon system.

Improvements in technology often ease the topside congestion. The introduction of the vertical launch Seawolf system (VLS) on the Type 23 Frigates (Figure A3.8) meant there was no longer a requirement to position two trainable launchers on the upper deck [Thomas & Easton 91] (Figure A3.9).

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Figure A3.8 : Vertical Launch Seawolf Silo [Janes 01]

Image removed due to third party copyright

Figure A3.9 : Trainable Seawolf Launcher [Janes 01]

The trade off is that the VLS system penetrates through a deck and takes up a large deck area. The benefit of the system is that once fired the missile has full coverage and is not limited by any blockages due to other equipment. Additionally the number of immediately available missiles is increased but no reload is possible.

Although it is often the major weapon systems that are seen to dominate the design, the smaller systems often have major impacts on the topside arrangement due to their individual requirements. This is best illustrated by considering the close in weapon systems (CIWS) placed on naval ships to provide last ditch defence against incoming missiles (Figure A3.10).

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Figure A3.10 : Phalanx and Goalkeeper CIWS [Janes 01]

These systems are automatic in operation, but by their nature are required to be self contained, have as wide a coverage as possible, be placed in positions where the maximum fire time is available and should not be limited in elevation or depression. This is often in competition with other major systems that require full coverage and tradeoffs must be made. All of these systems are highly complex and require regular maintenance, access has to be provided to allow the maintainers to carry out their work safely, and there is an additional requirement for the system to be reloaded. Provision has to be made for operations of this type and requires areas to be kept clear of other equipment and the equipment placed in such a position as to allow simple and safe reloading. The reloads must be kept close at hand in ready use lockers and these themselves require topside space and must meet the stringent requirements for safety.

3.3. Requirements for Aircraft

The requirement to support aircraft differs widely depending upon the role of the ship and dominates large sections of the topside arrangement for frigate and destroyer sized ships. The greatest requirements are placed upon aircraft carriers where the topside is almost exclusively given over to aircraft operations. The different designs that result are a consequence of the different operating philosophies and the aircraft types to be operated. In the UK the Invincible Class (Figure A3.11) meets the demands placed upon it by the Sea Harrier and Sea King aircraft [Honnor & Andrews 82].

Figure A3.11 : Invincible Class Aircraft Carrier [Janes 01]

In the United States Navy the aircraft carrier role is different and far higher demands are placed upon it, not only in numbers of aircraft, but also the type of aircraft. The power projection role of the vessel results in a far larger vessel (Figure A3.12). The Nimitz Class (91500 tonnes) is 332.9m long with a beam of 40.8m compared to the Invincible Class (20000 tonnes) at 206.6m length and beam of 27.5m [Janes 01].

Image removed due to third party copyright

Figure A3.12 : Nimitz Class Aircraft Carrier [Janes 01]

Although vastly different in size, the drivers for these ships are similar [Chapman 60], [Eddison & Groom 97], [Webb et al. 97], the flight deck is sized to allow for correct operation of the aircraft. Although the topside arrangement primarily supports aircraft the other necessary topside equipment must also be located resulting in some space being provided for this equipment and an island structure housing the required bridge, offices and mounts for sensors.

3.4. Requirements for Low Signatures

More recent designs have placed an increased emphasis on the requirement for low signatures. No single item is the dominating design driver, the overall concept of stealth drives the final solution. The French La Fayette Class of frigates (Figure A3.13) show how the stealth requirement, in particular reduced radar cross section, has driven the topside arrangement, with very little clutter[150], small boat equipment being placed behind rolling screens, with other equipment in wells or behind the bulwark [Friedman 96], [Janes 01]. This can be seen as a stylistic decision as well as a practical one as other solutions could have been reached to provide the same over stealth level.

Image removed due to third party copyright

Figure A3.13 : La Fayette Class Frigate [Janes 01]

In comparison to the UK Type 23 Frigate (Figure A3.3) the clutter is greatly reduced, however compromises have been made in the access requirements. The operating philosophy is different and will most likely be operated with a personnel free topside negating the need for safety rails and access walkways [Friedman 96]. A design decision has been made, driven by stealth, not to allow exterior access from forward to aft outside of the superstructure. The designer has to evaluate all decisions about individual equipment items against this particular and important design driver. Each individual system will still have the same constraints and requirements as it would have were it not being placed into a stealth driven design. It has been stated that ship design is engineering's greatest compromise [Purvis 74]. Tradeoffs have to be made as it is not possible to satisfy all design drivers at the same time. These tradeoffs may be minimised though different operating procedures but may result in inferior performance from a particular system and this has to be part of the compromise.

[150] Reduced topside clutter is an effective way to reduce the overall RCS signature [Turner & Barnes 00].

APPENDIX 4

4. RADAR DEFINITIONS AND APPROXIMATE RCS FORMULAE

4.1. Radar Definitions

To understand the simpler approaches adopted for preliminary design it is necessary to outline some basic radar concepts and definitions.

Radar

RADAR is an acronym for 'radio detection and ranging', the advantages of RADAR waves are that they suffer much less attenuation through the atmosphere than light and work at longer range than is possible visibly. The major advantage is that range information is captured in the returning signal [Knott et al. 85].

Radio waves travel at the speed of light, ($c=2.9979\times10^8$m/s), by measuring the time gap (Δt) between sending and receiving the signal the distance of the object can be established [Knott et al. 85].

$$\text{Range} = c\,\Delta t / 2 \qquad \textit{Equation A4.1}$$

Range provides information which when combined with the signal direction can be used to pinpoint the detected object.

Radar Cross Section[151]

The Radar Cross Section, (σ), of a body is defined as:-

"The projected area which would be required to intercept and radiate isotropically the same power as the target radiates towards the radar receiver." [Knott et al. 85]

[151] RCS is calculated in terms of m^2 however the large variations that can occur results in RCS often being presented in logarithmic form in dB relative to a square metre, $\sigma_{dBsm}=10.\log_{10}(\sigma)$.

Radar Equation

The radar (range) equation provides the mathematical relationship available to the engineer in assessing both the need for, and the resulting effectiveness of, reducing the target cross section. Its complete form represents:-

- Radar system parameters
- Target parameters
- Background effects (clutter and noise)
- Propagation effects (refraction and diffraction)
- Propagation medium (absorption and scatter) [Knott et al. 85]

The simplest form of the Radar Equation (derived in more detail in Appendix 4.1.1) is shown below, the received power, (P_r) is:-

$$P_r = P_t\, G^2\, \lambda^2\, \sigma \,/\, (4\pi)^3\, R^4 \ \text{(watts)} \qquad \textit{Equation A4.2}$$

This form of the Radar Equation does ignore some detail which may be critical for radar performance analysis. But for rough analysis is does give a good guide to evaluating the changes of the received power with radar cross section.

Maximum Detectable Range

The minimum received power can be defined as the lowest power required by the receiver to detect the difference between a target and noise (signal-to-noise ratio). If the minimum received power is known for an antenna then Equation 6.2 can be rearranged as a function of the maximum detectable range (R_{max}):-

$$R_{max} = [P_t\, G^2\, \lambda^2\, \sigma \,/\, (4\pi)^3\, P_{min}\,]^{1/4} \ \text{(m)} \qquad \textit{Equation A4.3}$$

Note that equation 6.3 shows that for a 12 dB reduction in the RCS the maximum detectable range varies by 3 dB, which is equivalent to halving the maximum detection range [Knott et al. 85].

Scattering Regimes

An electromagnetic wave impinging upon an object induces a current in the body called the 'scattering field'. Some of the electromagnetic energy is radiated in all directions with variable phase and amplitude. The nature of the reflected electromagnetic energy can fall into 3 distinct regions dependent on the wavelength and body size. A simple case to demonstrate these regions is with the RCS of a sphere as it is independent of direction.

Image removed due to third party copyright

Figure A4.1 : Different Frequency Regimes for a Sphere [Knott et al. 85]

Figure A4.1 shows the RCS results (normalised with respect to the geometric cross section πa^2) obtained for a sphere for a range of ka values, where a is the radius of the sphere and k is the wave number ($2\pi/\lambda$). For values between $0.1 \leq ka \leq 1$ the radar wave length is greater than the radius of the sphere and the radar cross section is small but increases as the fourth power of frequency, proportional to $(ka)^4$. For $1 \leq ka \leq 10$ there is strong oscillatory behaviour known as the resonant region. When $10 \leq ka$, i.e. the wavelength is small compared to the size of the body, the oscillatory behaviour dies out and the RCS is constant and approaches the projected area of the sphere, this is known as the optics region [Knott et al. 85].

Ship structures are many metres long and the most common wavelength for RCS analysis, the X band is about 0.0325m long [Janes 01], and so the RCS prediction for ships falls into the optics region. Collective interactions[152] are very small, therefore the body can be treated as a collection of independent scatterers. [Knott et al. 85].

4.1.1. The Radar Equation

The radar (range) equation provides the mathematical relationship available to the engineer in assessing both the need for, and the resulting effectiveness of, reducing the target cross section. Its complete form represents:-

- Radar system parameters
- Target parameters
- Background effects (clutter and noise)
- Propagation effects (refraction and diffraction)
- Propagation medium (absorption and scatter) [Knott et. al. 85]

Power intercepted can be shown as:-

$$\text{Power intercepted} = P_t\, G_t\, \sigma / 4\, \pi\, R^2 \text{ (watts)} \qquad \textit{Equation A4.4}$$

where
P_t = radar transmitter power
G_t = gain of transmitter antenna[153]
σ = RCS of target
R = distance from antenna

For isotropic radiation the power density at the radar receiver can be defined as:-

$$\text{Power density} = P_t\, G_t\, \sigma / (4\pi)^2\, R^4 \text{ (watts / m}^2\text{)} \qquad \textit{Equation A4.5}$$

[152] The field at any point on the body is the sum of the incident field and a scattered field due to every part of the body. This collective interaction determines the resultant current density. When considering the optics region the influence of the scattered field is very small [Knott et al. 85].
[153] The ratio of the power radiated in a particular direction by an antenna to that radiated in the same direction by a perfectly efficient isotropic antenna [Knott et al. 85].

The received power is therefore a function of the power density and the capture area of the antenna. We can define the capture area in terms of receiving antenna gain:-

$$A_c = G_r \lambda^2 / 4\pi (m^2)$$ *Equation A4.6*

where A_c = capture area
G_r = gain of receiver antenna
λ = wavelength

If it is assumed that the same antenna is used for both transmission and reception, then:-

$$G_t = G_r = G.$$ *Equation A4.7*

The simplest form of the Radar Equation can now be shown, as the received power, (P_r) is:-

$$P_r = P_t G^2 \lambda^2 \sigma / (4\pi)^3 R^4 \text{ (watts)}$$ *Equation A4.8*

4.2. Approximate RCS Formulae

4.2.1. Approximate RCS Formula for Flat Plates

Flat plates can be used to represent a large proportion of the ship topside structure. The following formula represents the RCS contribution from a plate that is flat (compared to the radar wavelength) of dimensions a and b along the x and y axes respectively [Maffet 89].

$$\sigma = \frac{4\pi a^2 b^2}{\lambda^2}\left[\frac{\sin\left(k\left(\frac{b}{2}\right)\sin\theta\sin\phi\right)}{k\left(\frac{b}{2}\right)\sin\theta\sin\phi}\right]^2\left[\frac{\sin\left(k\left(\frac{a}{2}\right)\sin\theta\cos\phi\right)}{k\left(\frac{a}{2}\right)\sin\theta\cos\phi}\right]^2$$

for $0 <= \theta <= \pi/2$, $-\pi/2 <= \phi <= \pi/2$

Equation A4.9

The co-ordinate system can be shown in the following diagram. The spherical co-ordinate system used by the equation has to be applied to the plate, where we conventionally think of an azimuth and elevation in terms of orthogonal axes. The spherical co-ordinate system does not easily lend itself to analysing the RCS of the plate from a plane intercepting it off normal. A conversion is needed to use the information of the tilt of the plate and the position on the azimuth to calculate the values of θ and ϕ[154].

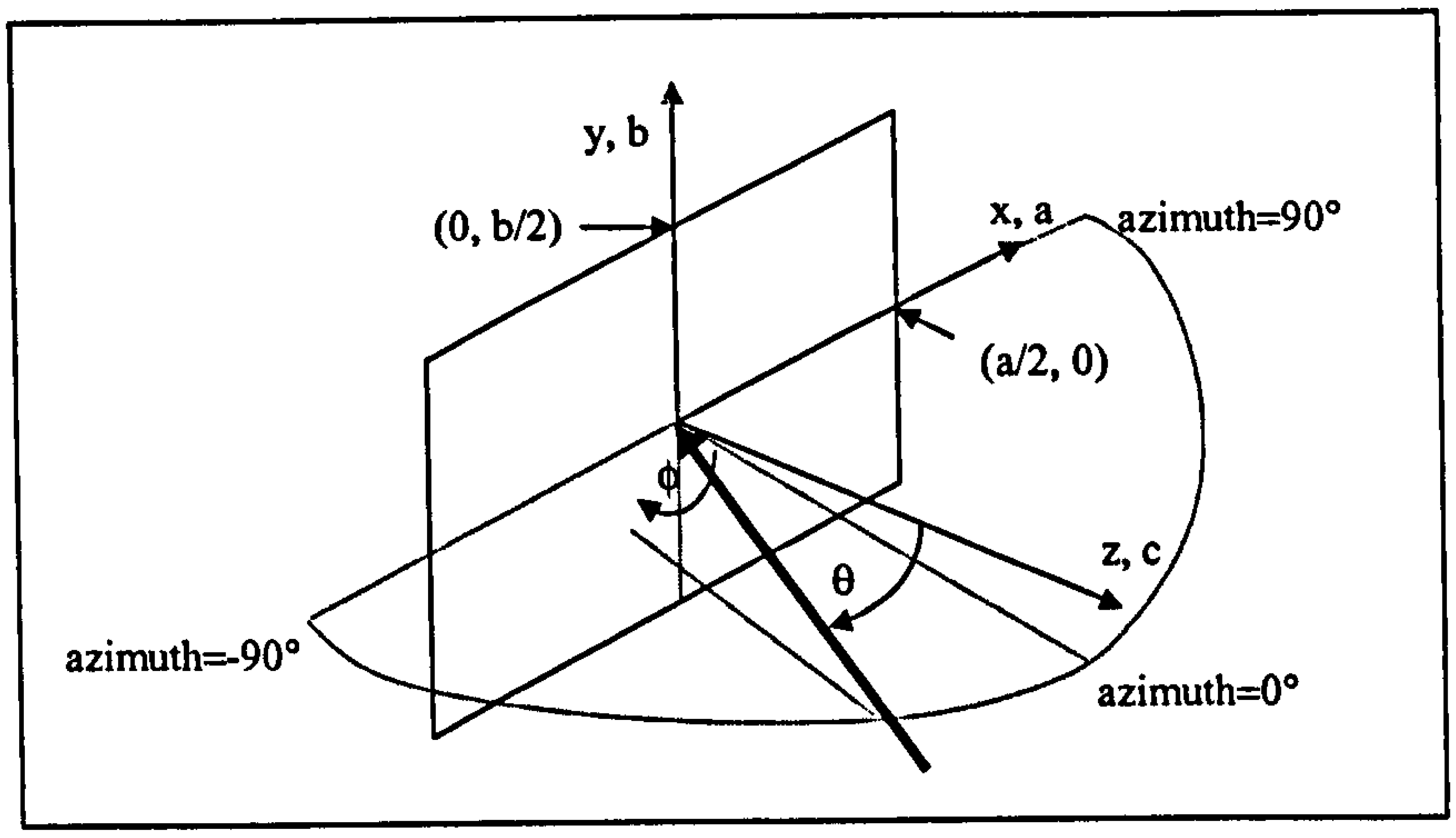


Figure A4.2 : Co-ordinate System for the Flat Plate

4.2.2. Approximate RCS Formulae for Elliptical and Circular Cylinders

Elliptical and circular cylinders can be used to represent curved masts or funnels. It should be noted that if the cylinder is tilted the radar will see an elliptical cross section different to that on the principal xy plane.

The following formulae were used [Maffet 89]:-

$$\sigma = \frac{2\pi(Lab)^2}{\lambda\left(a^2\cos^2\phi + b^2\sin^2\phi\right)^{3/2}} \qquad \text{for } \theta = \pi/2$$

$$\sigma = \frac{\lambda(ab)^2\sin\theta}{8\pi\cos^2\theta\left(a^2\cos^2\phi + b^2\sin^2\phi\right)^{3/2}} \qquad \text{for } \theta \neq \pi/2$$

Equation A4.10

There are two components to this equation due to the reactions from either end of the cylinder. If the cylinder is connected to a surface at one end there will only be one

[154] This axis conversion is discussed by Way and included in the SIRCS RCS prediction code developed at UCL [Way 97].

return. If a = b then the formula would calculate the approximate RCS for a circular cylinder.

4.2.3. Approximate RCS Formula for Prolate, Oblate and Spherical Ellipsoids

Certain structures on a ship may be modelled by ellipsoids. For example they may be able to model gun casings (such as the 4.5″ gun) or small radars. The formula is shown below [Maffet 89]:-

$$\sigma = \frac{\pi(abc)^2}{\left(a^2 \sin^2\theta\cos^2\phi + b^2\sin^2\theta\sin^2\phi + c^2\cos^2\theta\right)^2}$$

Equation A4.11

Prolate spheroid	$a = b < c$
Oblate spheroid	$a = b > c$
Sphere	$a = b = c$

4.2.4. Chu's Formula for the Approximate RCS of Thin Wires

When RCS calculations are made of the leading edge of aircraft it is quite common to represent the edge effect by simulating a thin wire as the edge. Like a corner a thin wire is many times longer than the wavelength but the diameter is much smaller than the wavelength. A corner is never truly sharp so representing it as a small radius gives good comparison with an actual edge.

The RCS of a perfectly conducting wire which is many wavelengths long but only a fraction of a wavelength in diameter can be calculated by the following simple formula (Chu's formula) which is in good agreement with experiment [Crispin & Maffet 65a]:-

$$\sigma = \frac{\pi L^2 \sin^2\theta \left\{\dfrac{\sin\left[\left(2\pi L/\lambda\right)\cos\theta\right]}{\left(2\pi L/\lambda\right)\cos\theta}\right\}^2}{\left(\dfrac{\pi}{2}\right)^2 + \left(\ln\dfrac{\lambda}{\gamma\pi a \sin\theta}\right)^2}\cos^4\phi$$

Equation A4.12

Where a = length / radius of the wire and can vary between 225 and 900.

4.3. Relative and Random Phase Methods

Once the various RCS contributions have been calculated their quantities must be summated together at each azimuth angle. This can be conducted by one of two methods [Crispin & Maffet 65b]:-

1. The Relative Phase Method
2. The Random Phase Method

The Relative Phase Method involves the consideration of the relative phase angles between each scatterer. The following formula may be used [Crispin & Maffet 65b]:-

$$\sigma_p = \left|\sum_{j=1}^{N} (\sigma_j)^{1/2} \exp(i\phi_j)\right|^2$$ *Equation A4.13*

where σ_j = RCS of the j^{th} element

ϕ_j = relative phase of the j^{th} element.

But for large objects at small wavelengths this method can prove to be inaccurate, therefore the Random Phase Method should be used which gives an 'average' RCS [Crispin & Maffet 65b].

The Random Phase Method is based on the assumption that there are many different phase angles and these are randomly distributed, so when these are averaged the following equation results [Crispin & Maffet 65b]:-

$$E[\sigma] = \sum_{j=1}^{N} \sigma_j$$ *Equation A4.14*

We can also estimate the probable deviation from the average cross section $E[\sigma]$, by employing the root mean squared (rms) approach. The probable RCS then lies in the range given by $E[\sigma] \pm S$, where S is the rms spread defined by [Crispin & Maffet 65b]:-

$$S = \left|\sum_{j=1}^{N} \sqrt{\sigma_j}\right|^2$$ *Equation A4.15*

This method gives an RMS spread indicative of the amount by which the RCS might deviate from the average value due to phase effects [Crispin & Maffet 65b].

For an order-of-magnitude estimation of the RCS made up of simple shapes at specific azimuth angles the Random Phase Method is adequate. But if information is required about the variation of the RCS due to phase changes then the Relative Phase method should be used [Crispin & Maffet 65b].

APPENDIX 5

5. RESULTS FROM THE APPLICATION OF RCS PREDICTION TECHNIQUES

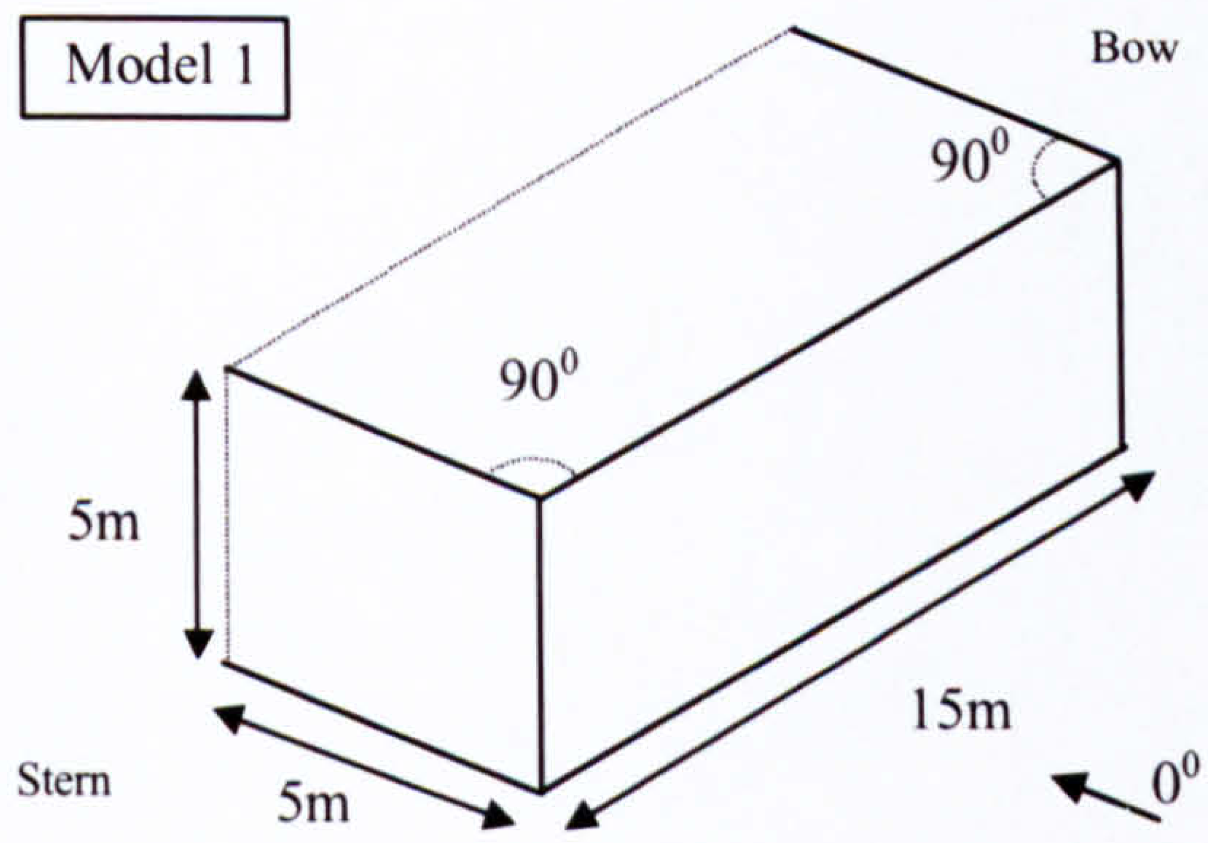
5.1. Model Details and Results

Results are presented for the 19 models detailed below.

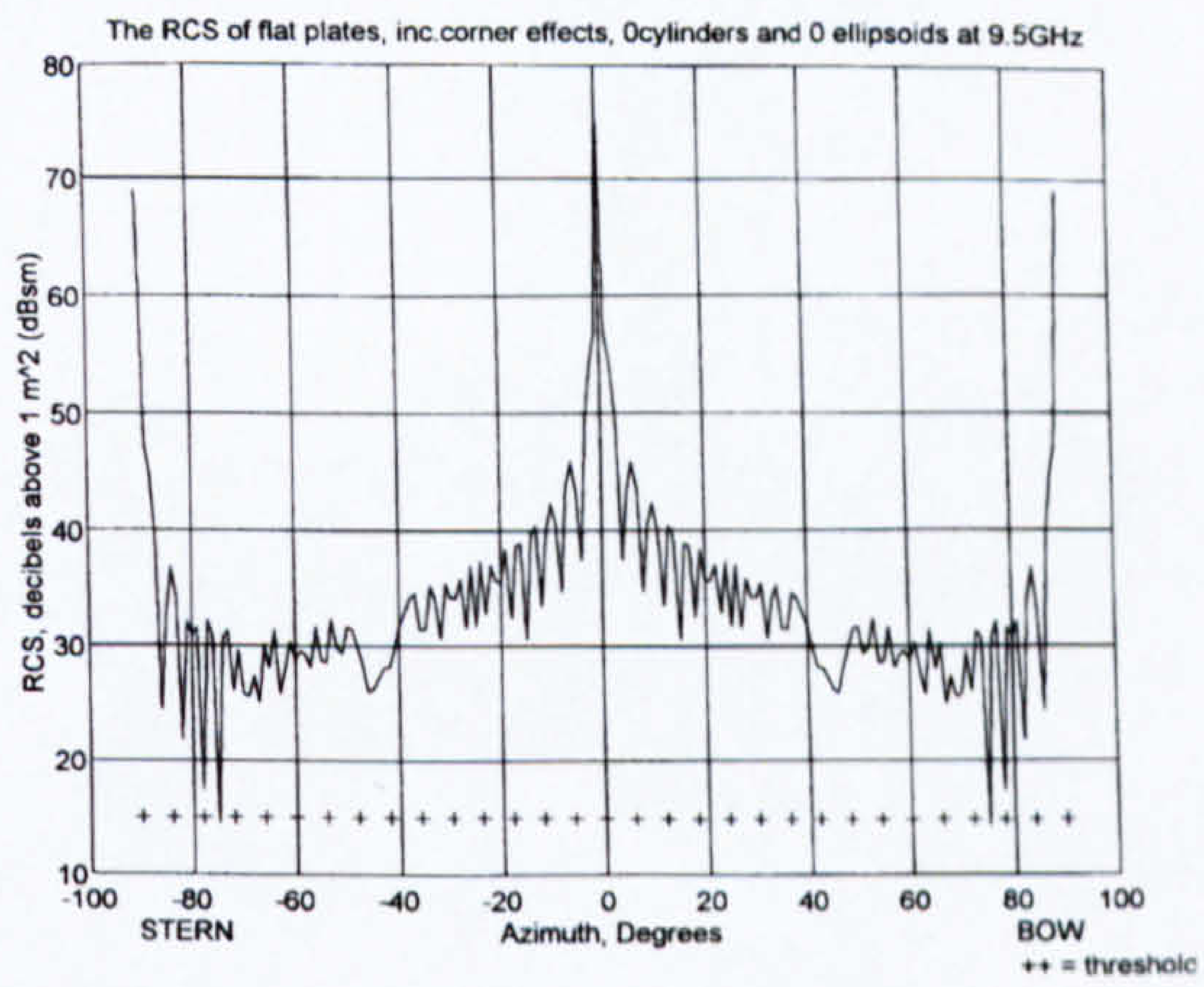
Model 1 :	Simple box, all plates at 0°
Model 2 :	Simple box, all plates at 5°
Model 3 :	Simple box, all plates at 10°
Model 4 :	Box with chamfer at 30° with 0° incline, 3 plates at 7° incline
Model 5 :	Box with chamfer at 30° with 7° incline, 3 plates at 7° incline
Model 6 :	Box with chamfer at 45° with 0° incline, 3 plates at 7° incline
Model 7 :	Box with chamfer at 45° with 7° incline, 3 plates at 7° incline
Model 8 :	Box with chamfer at 60° with 0° incline, 3 plates at 7° incline
Model 9 :	Box with chamfer at 60° with 7° incline, 3 plates at 7° incline
Model 10 :	Base with 7° incline with square mast at 0° incline
Model 11 :	Base with 7° incline with square mast at 7° incline
Model 12 :	Base with 7° incline with circular mast at 0° incline
Model 13 :	Base with 7° incline with circular mast at 5° incline
Model 14 :	Base with 7° incline with circular mast at 10° incline
Model 15 :	Base with 7° incline with oval funnel at 0° incline
Model 16 :	Base with 7° incline with oval funnel at 5° incline
Model 17 :	Base with 7° incline with oval funnel at 10° incline
Model 18 :	Base with 7° incline with short square mast at 7° incline
Model 19 :	Base with 7° incline with tall square mast at 7° incline

Model 1 : Simple box, all plates at 0°

Model Definition

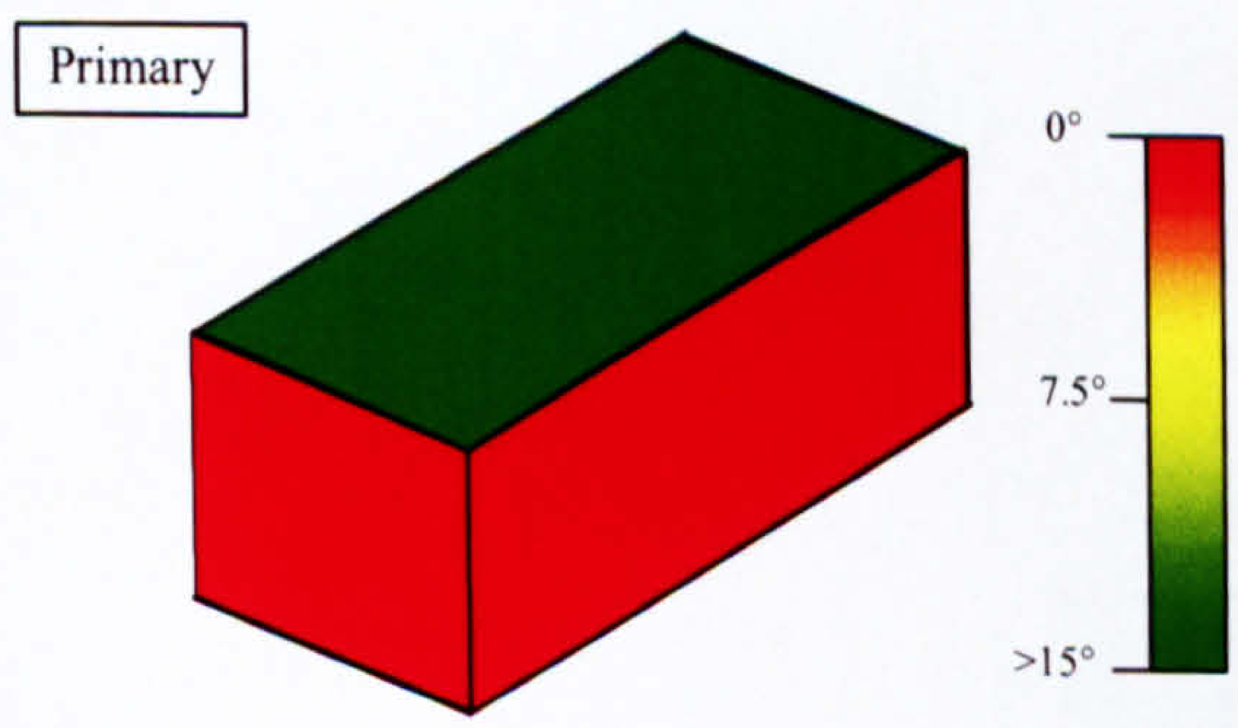


Results from SIRCS Analysis

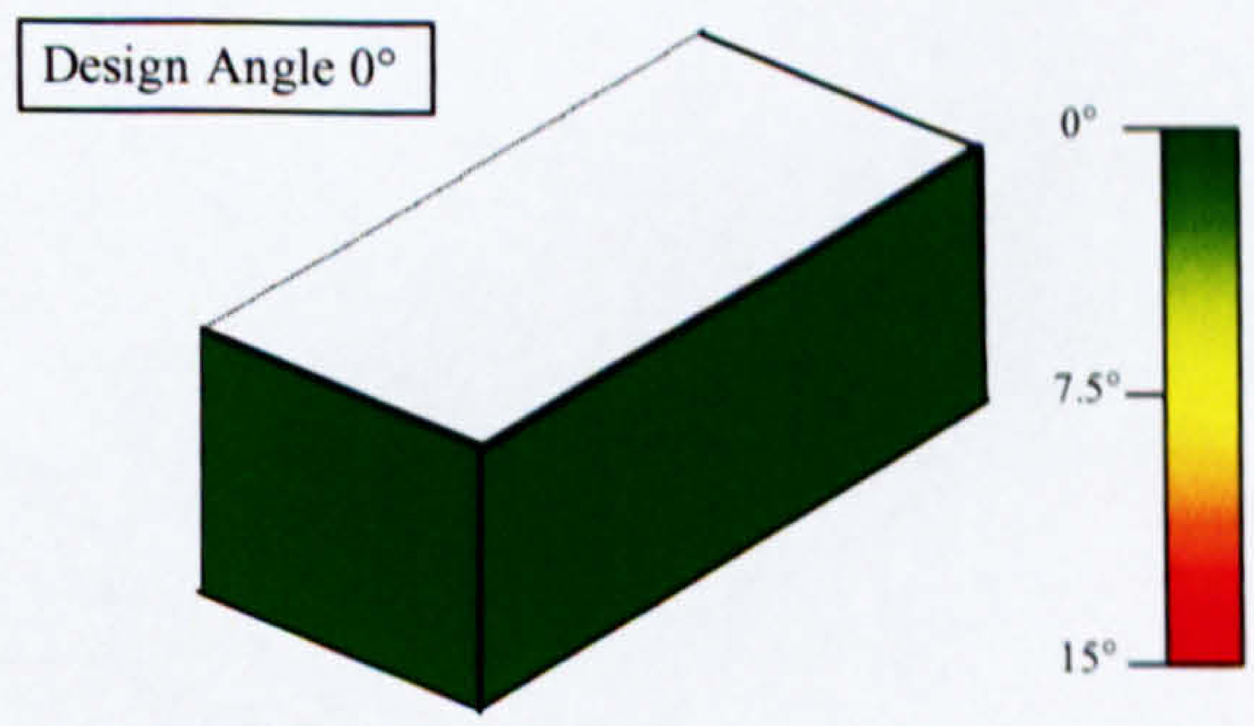


Results from the Geometric Analysis

a) Primary Reflections

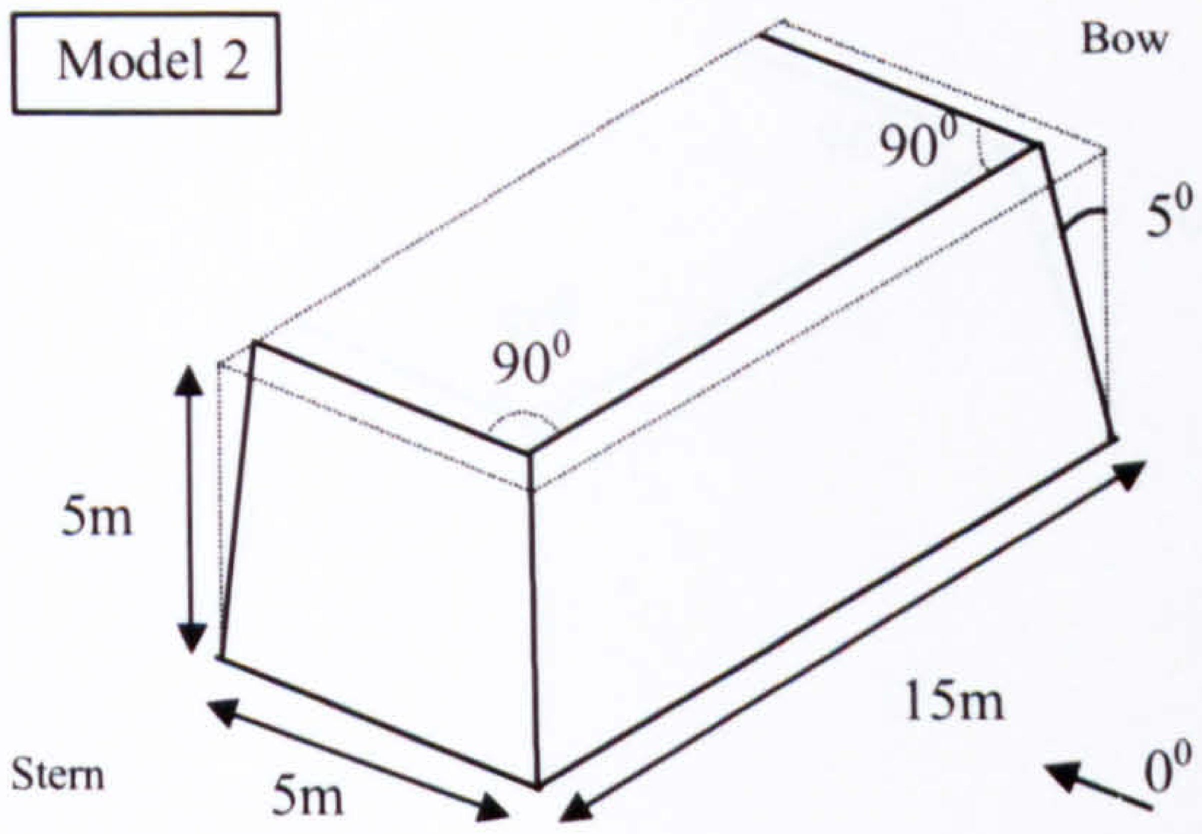


b) Design Angle Returns
Chosen design angle = 0°

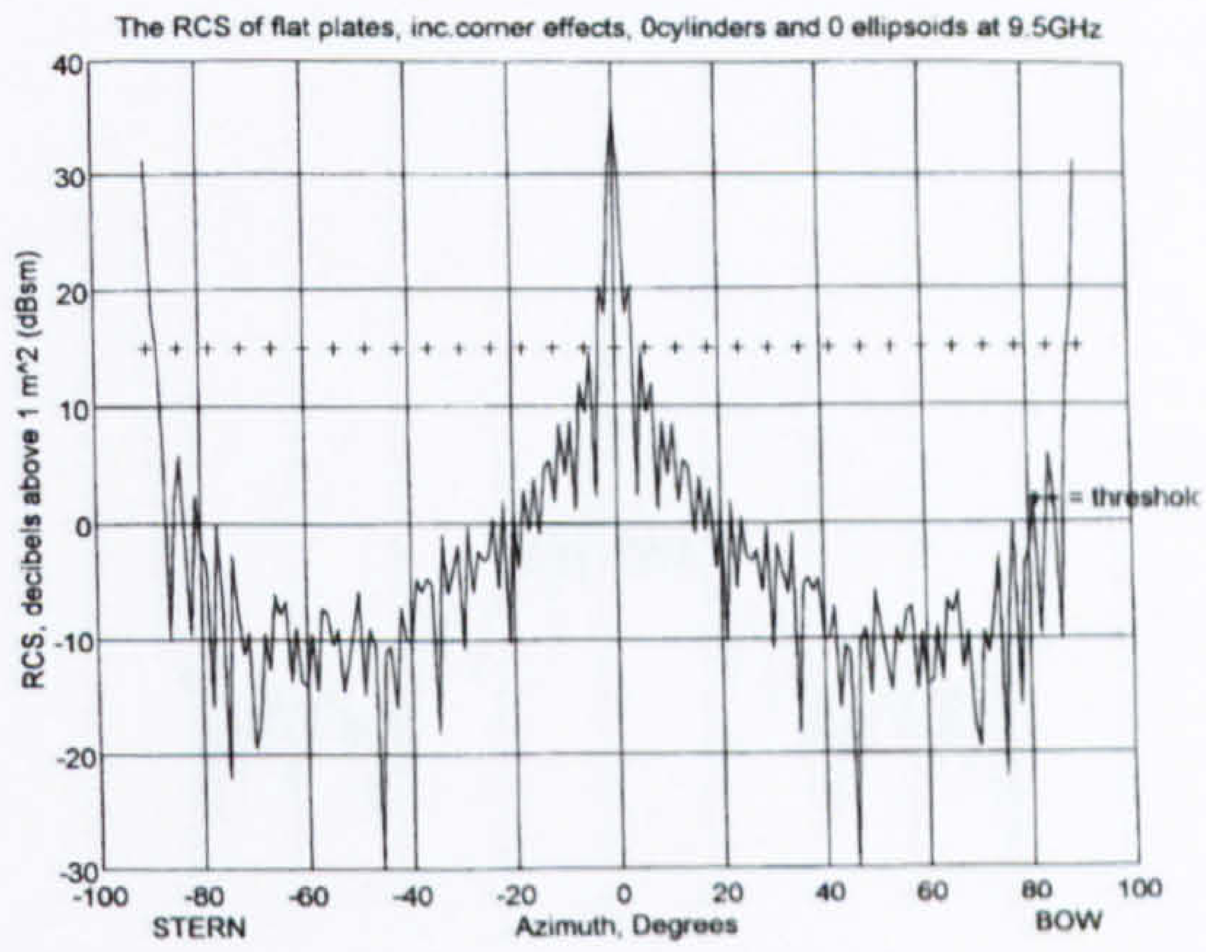


Model 2 : Simple box, all plates at 5°

Model Definition

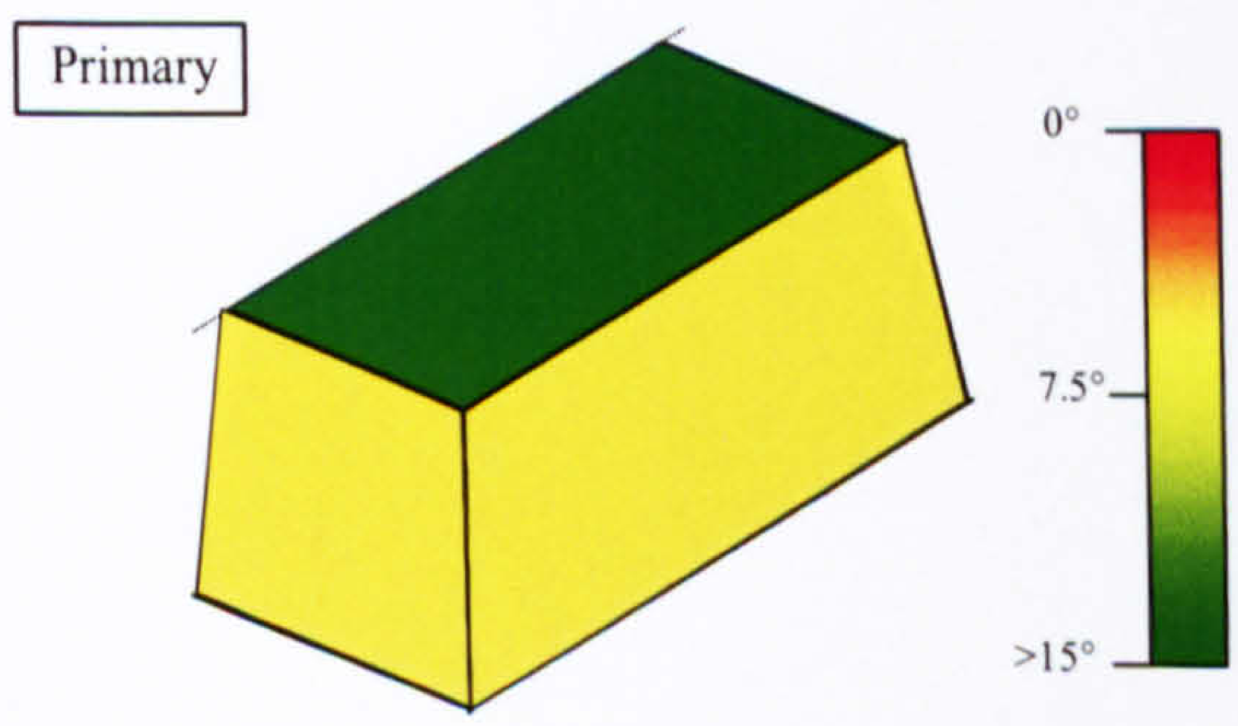


Results from SIRCS Analysis

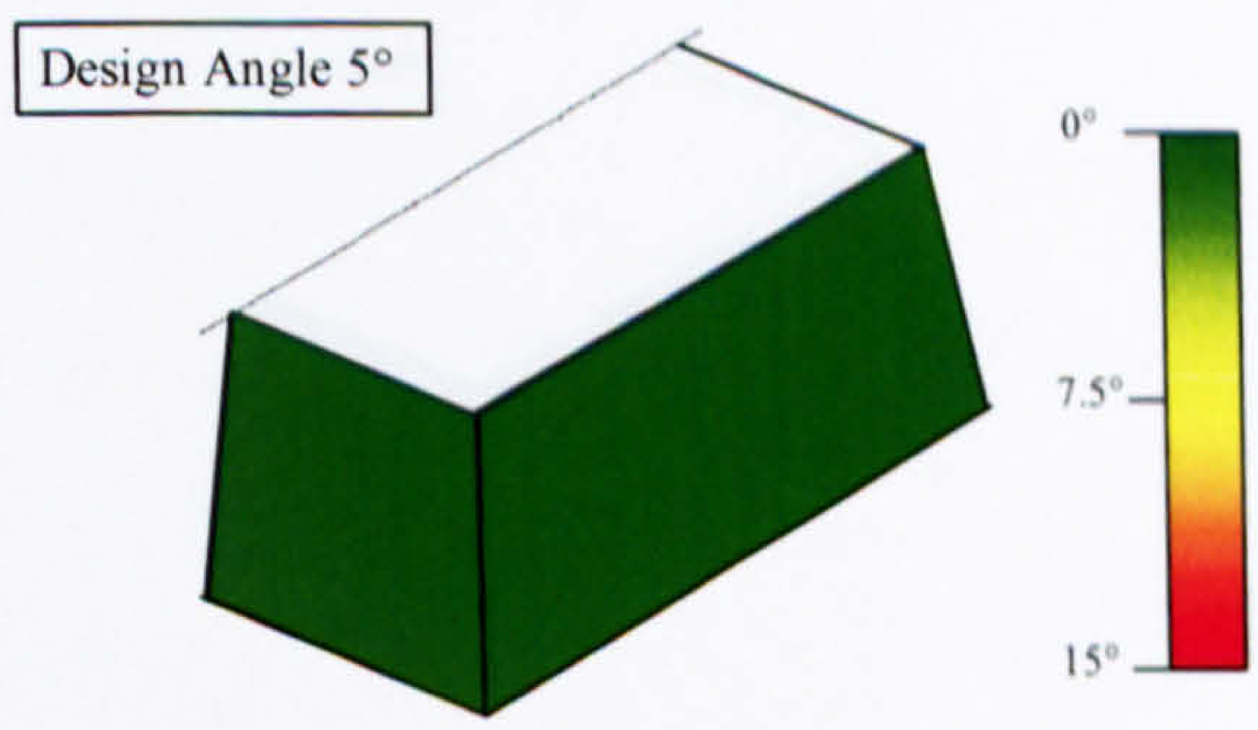


Results from the Geometric Analysis

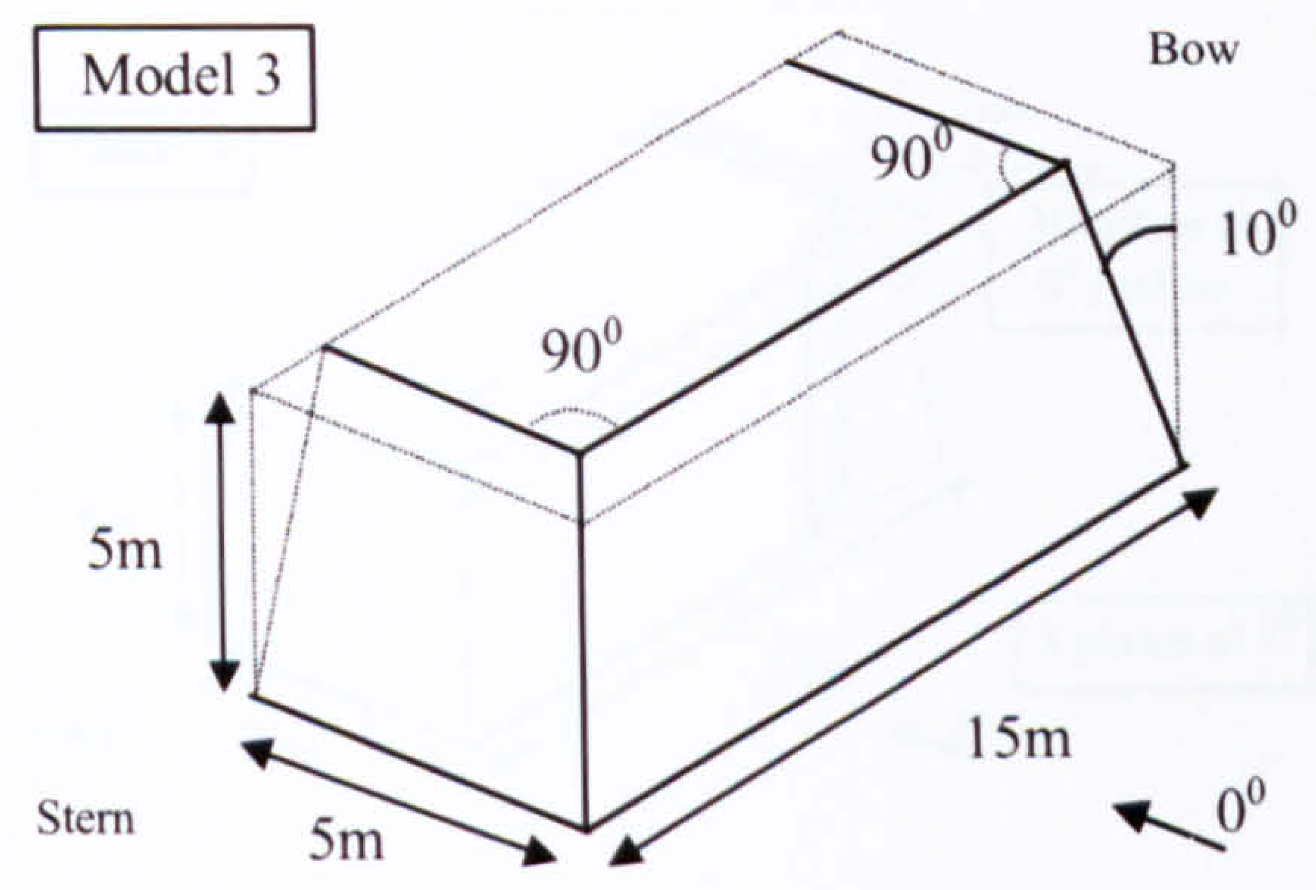
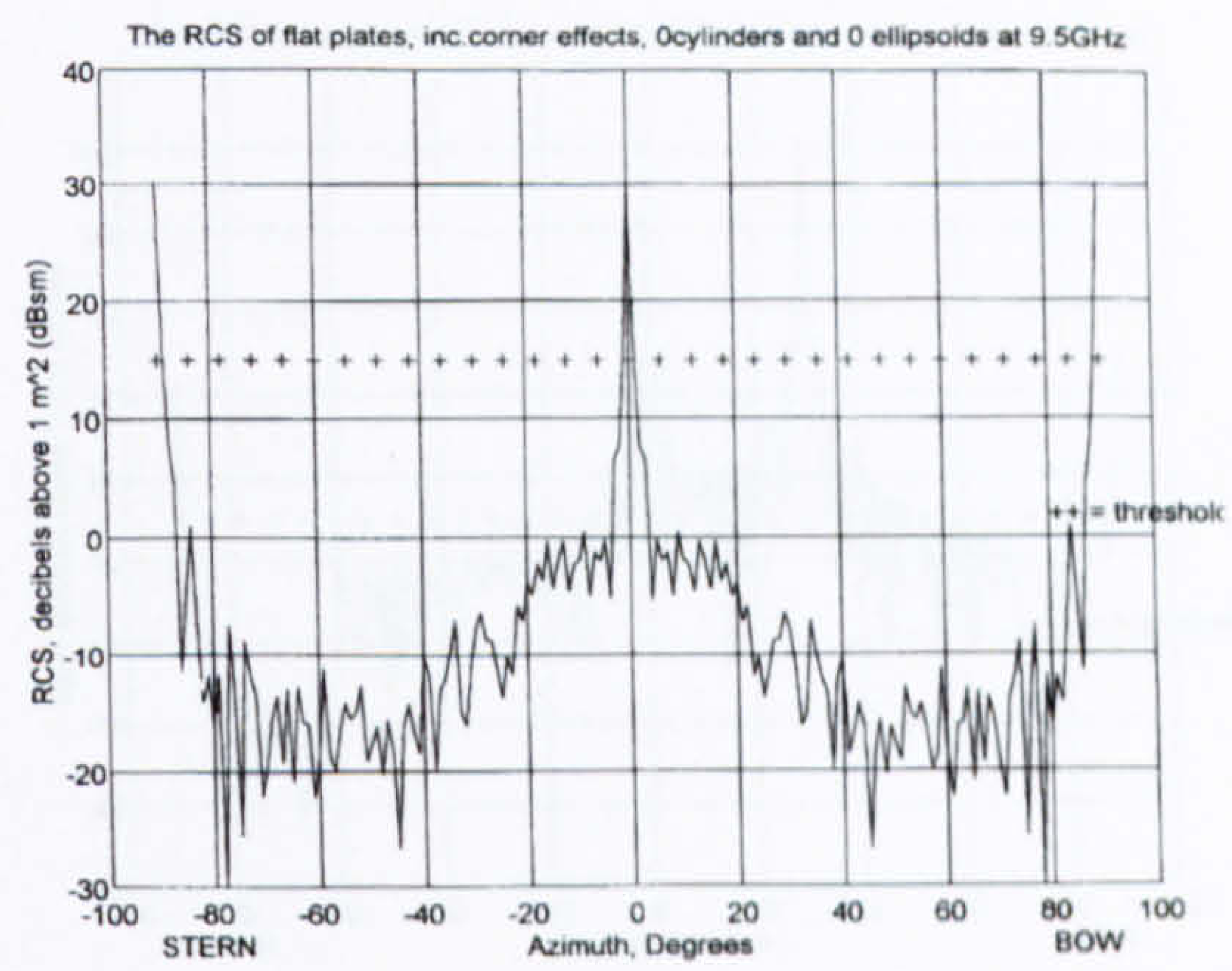
a) Primary Reflections



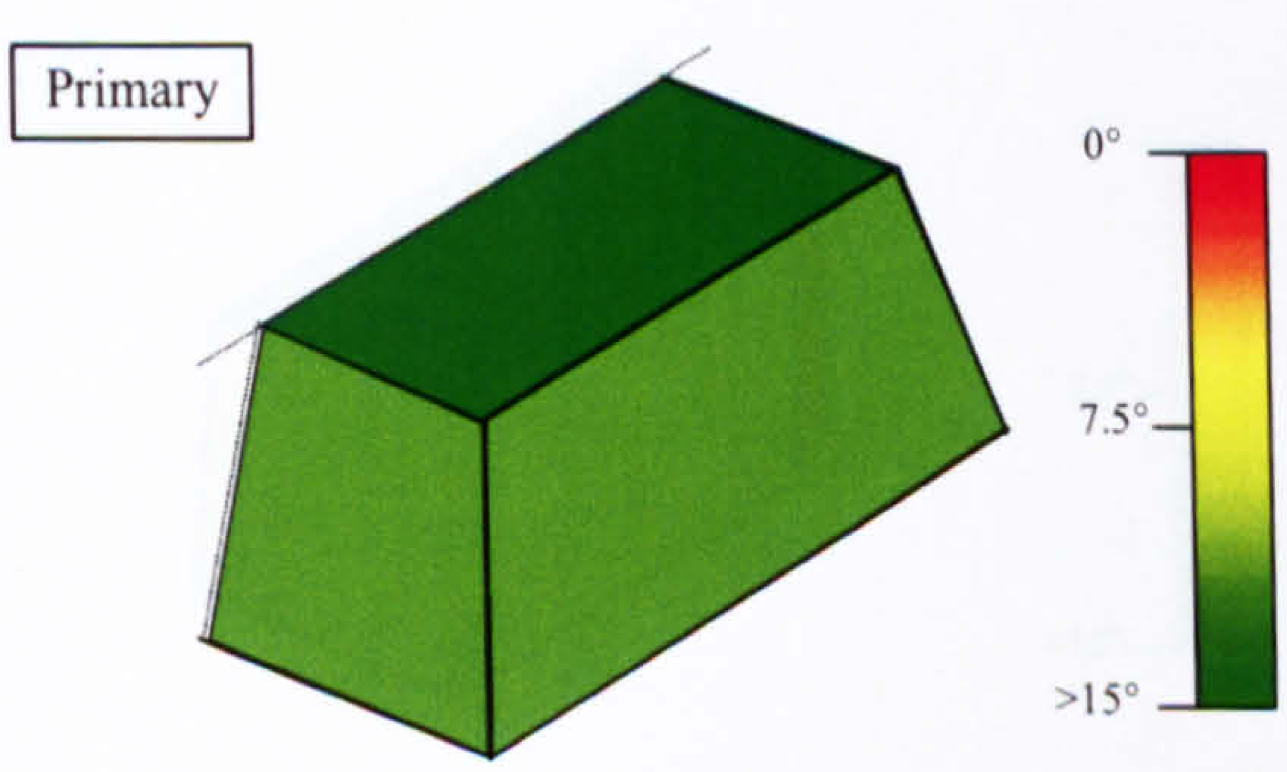
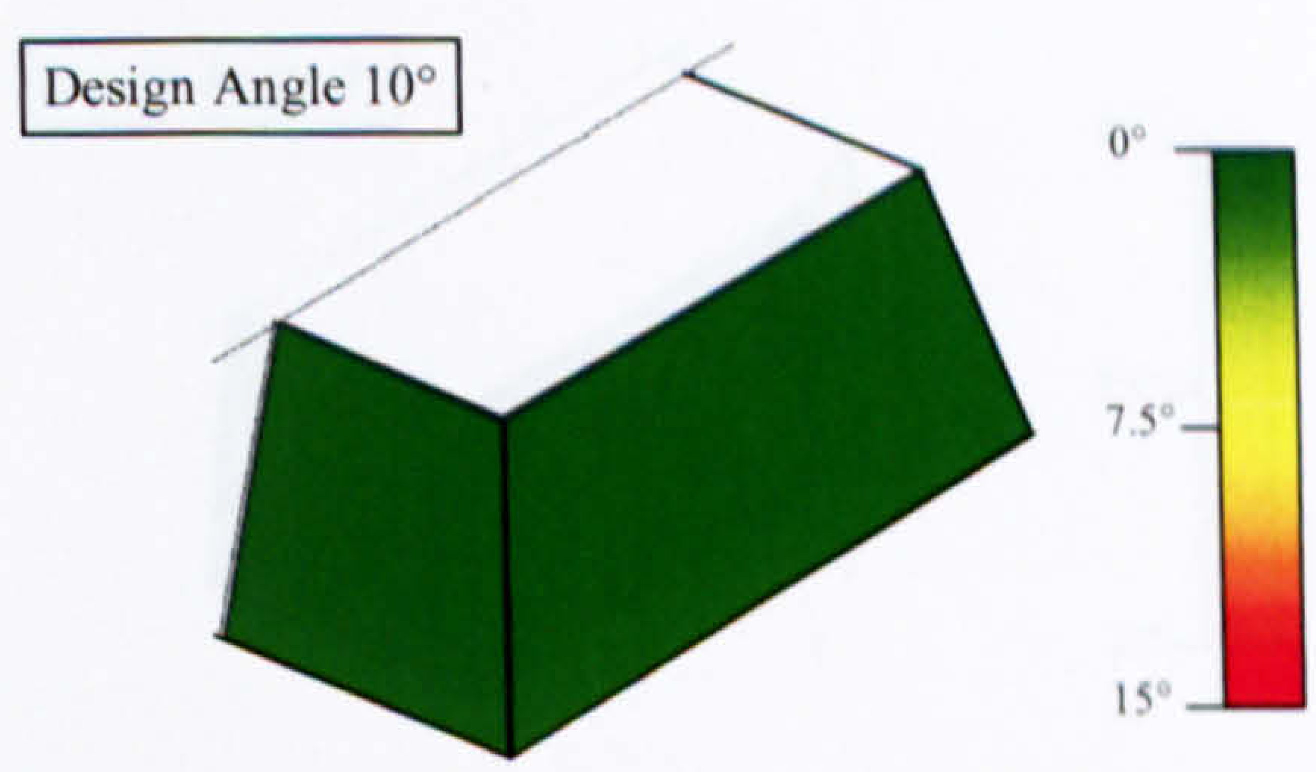
b) Design Angle Returns
Chosen design angle = 5°



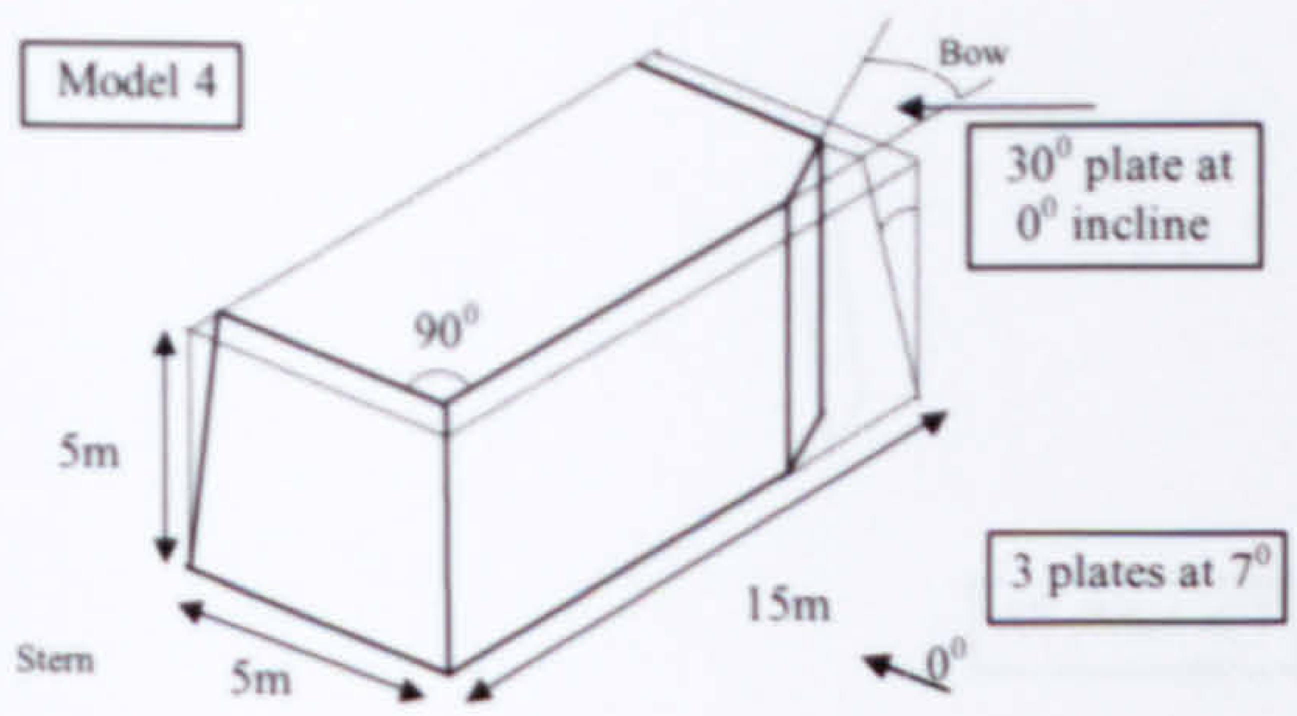
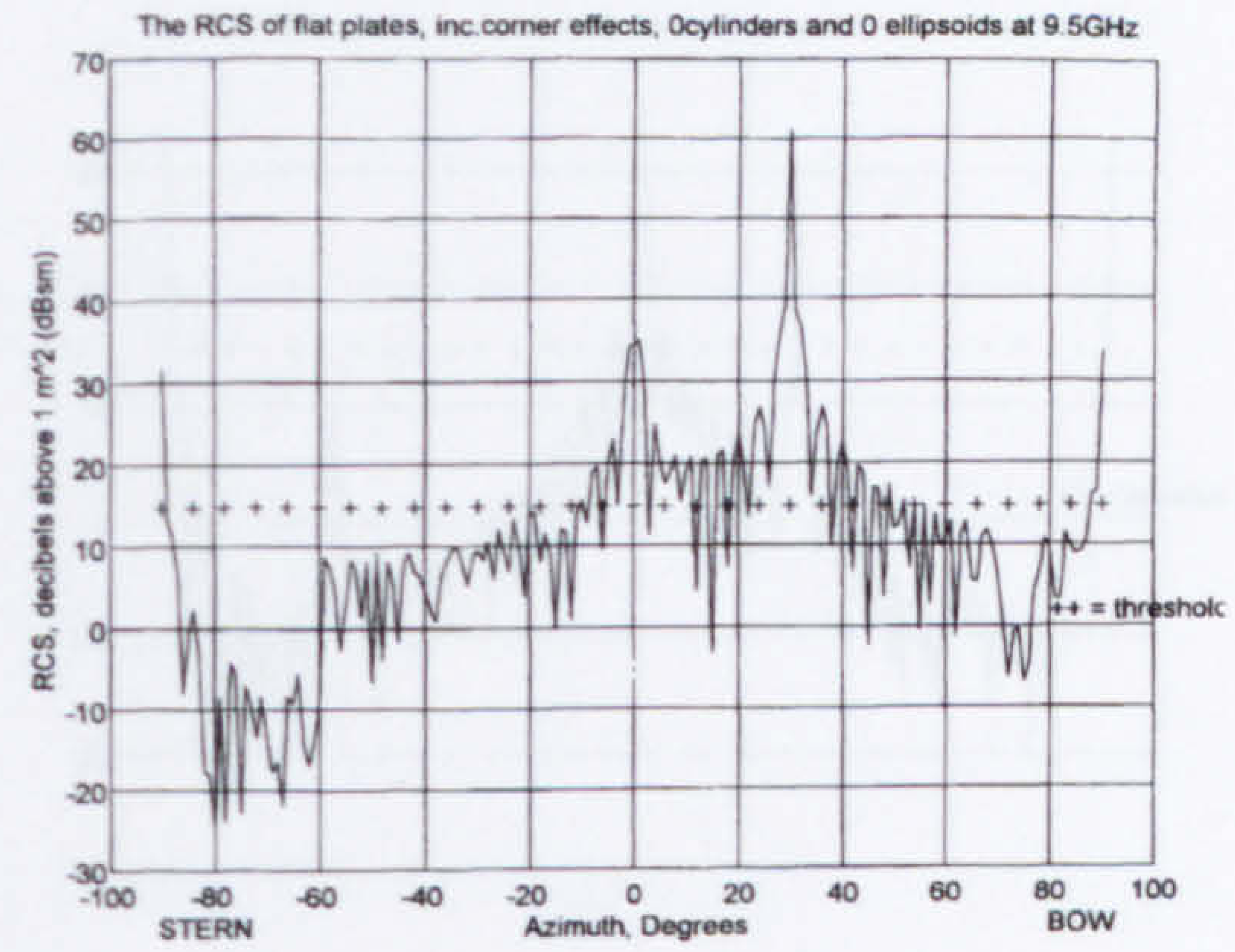
Model 3 : Simple box, all plates at 10°

Model Definition	Results from SIRCS Analysis
	

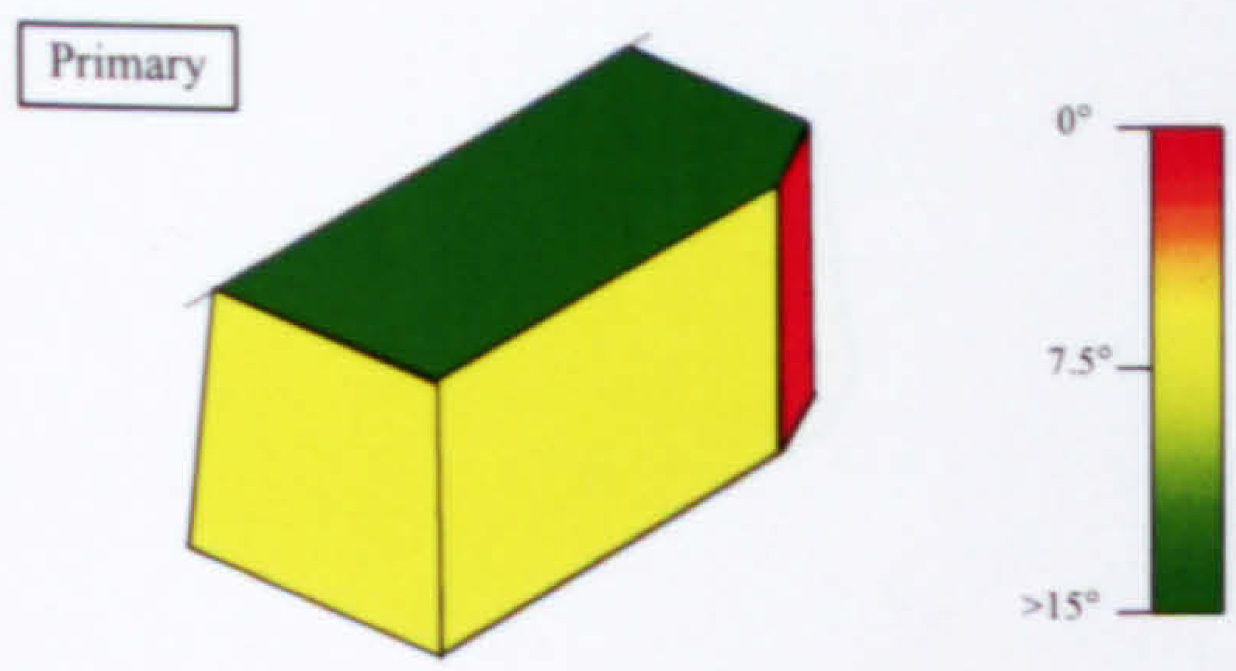
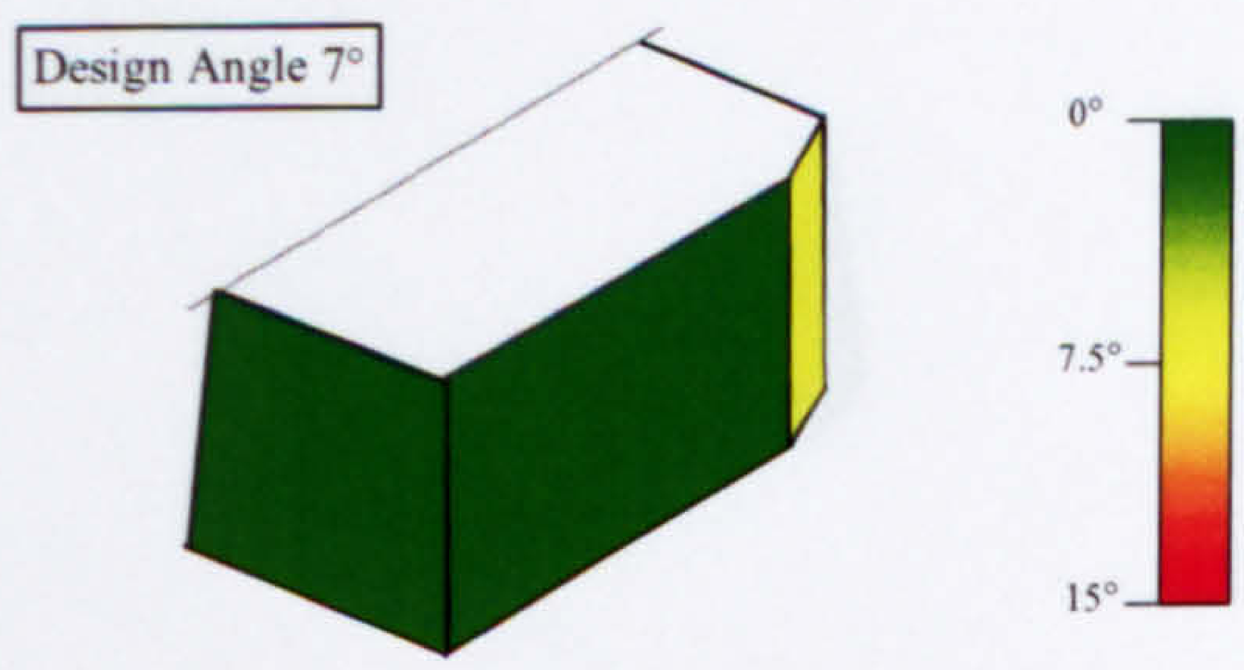
Results from the Geometric Analysis

a) Primary Reflections	b) Design Angle Returns Chosen design angle = 10°
	

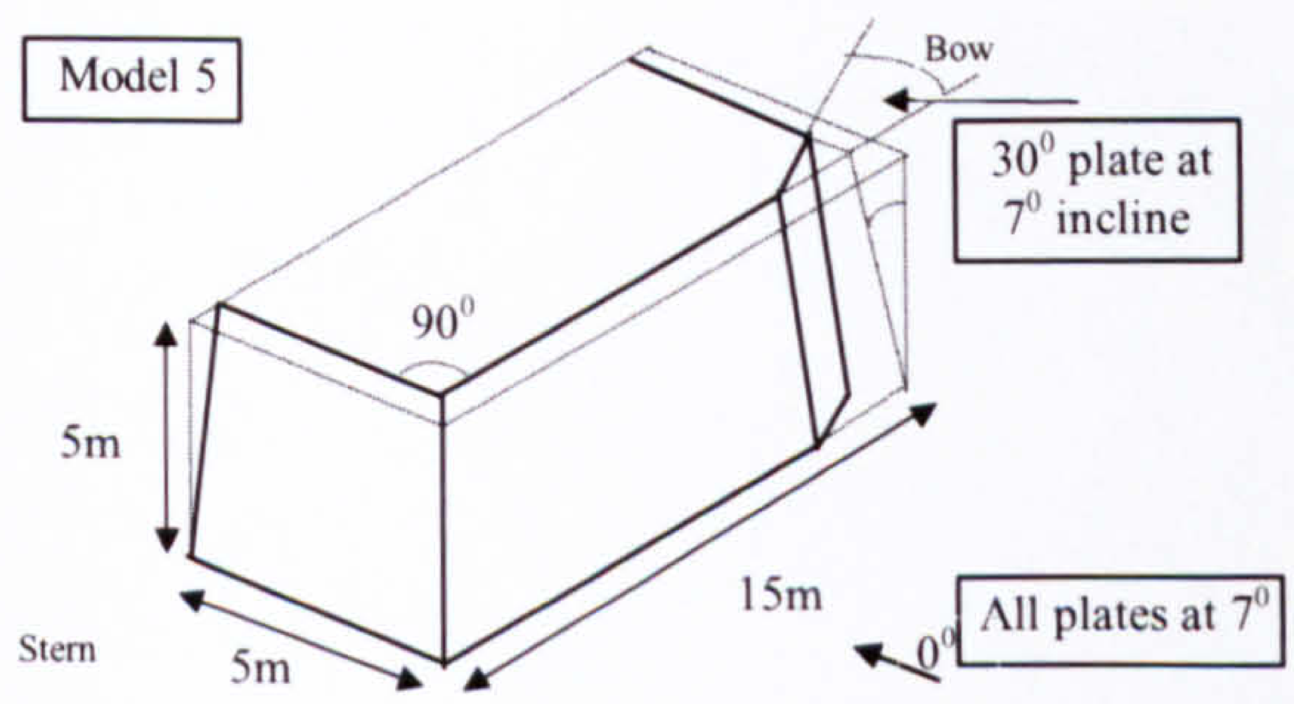
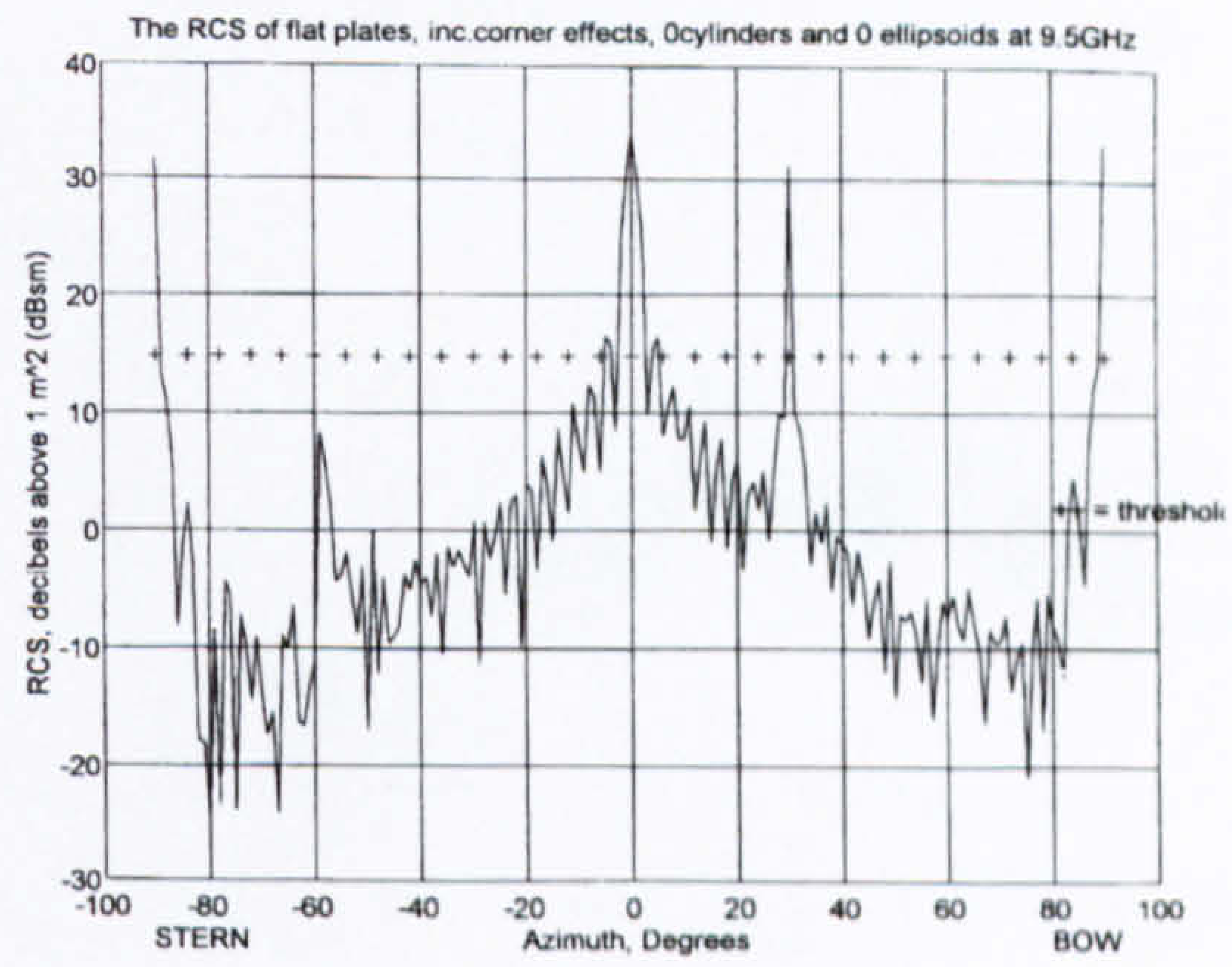
Model 4 : Box with chamfer at 30° with 0° incline, 3 plates at 7° incline

Model Definition	Results from SIRCS Analysis
	

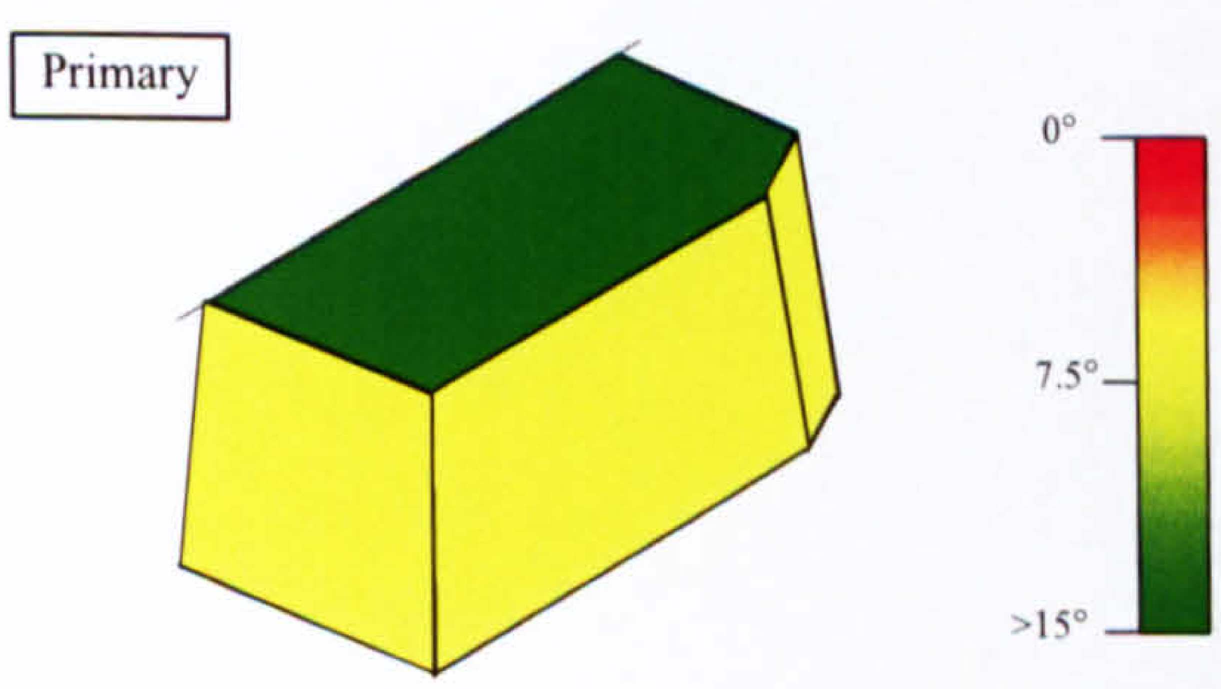
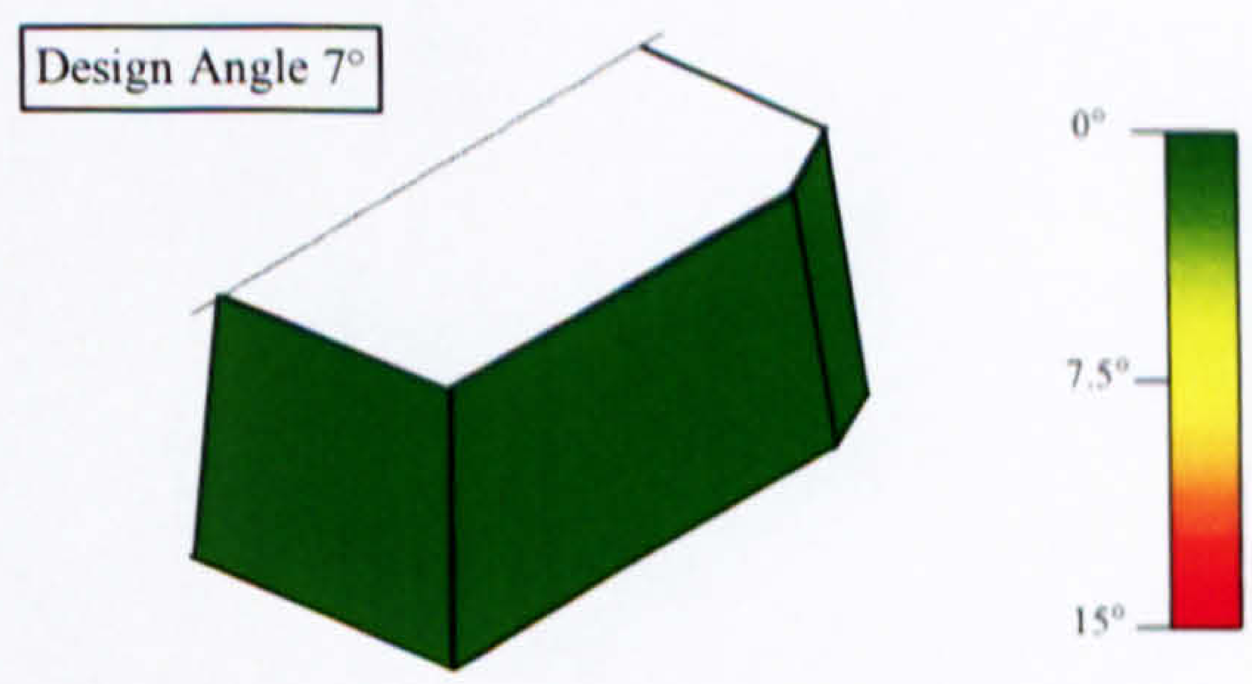
Results from the Geometric Analysis

a) Primary Reflections	b) Design Angle Returns Chosen design angle = 7°
	

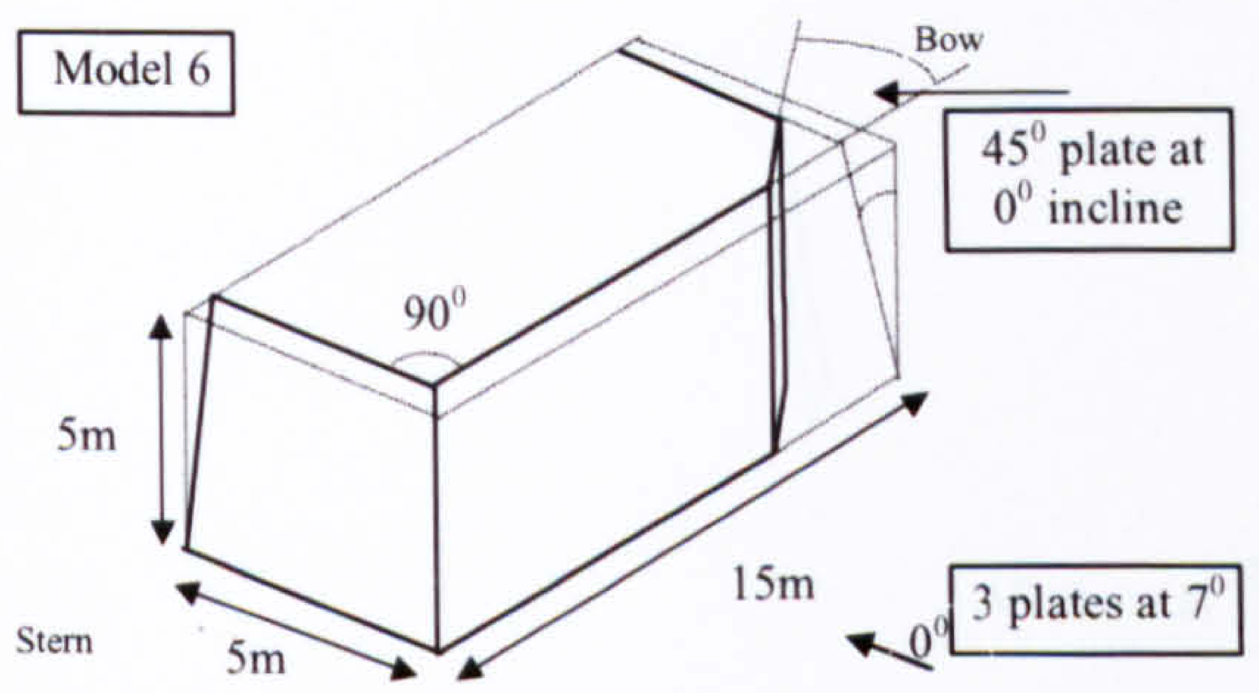
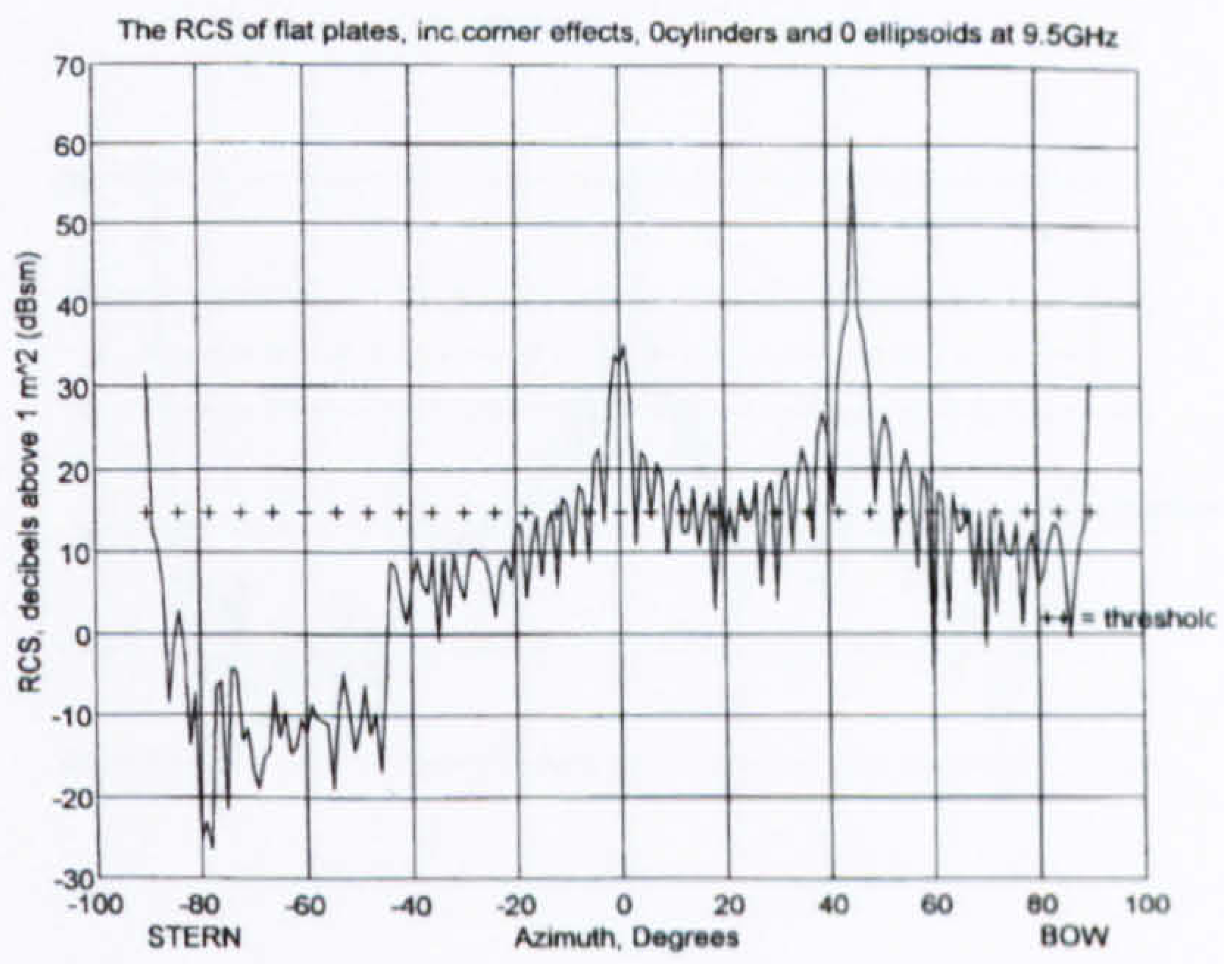
Model 5 : Box with chamfer at 30° with 7° incline, 3 plates at 7° incline

Model Definition	Results from SIRCS Analysis
	

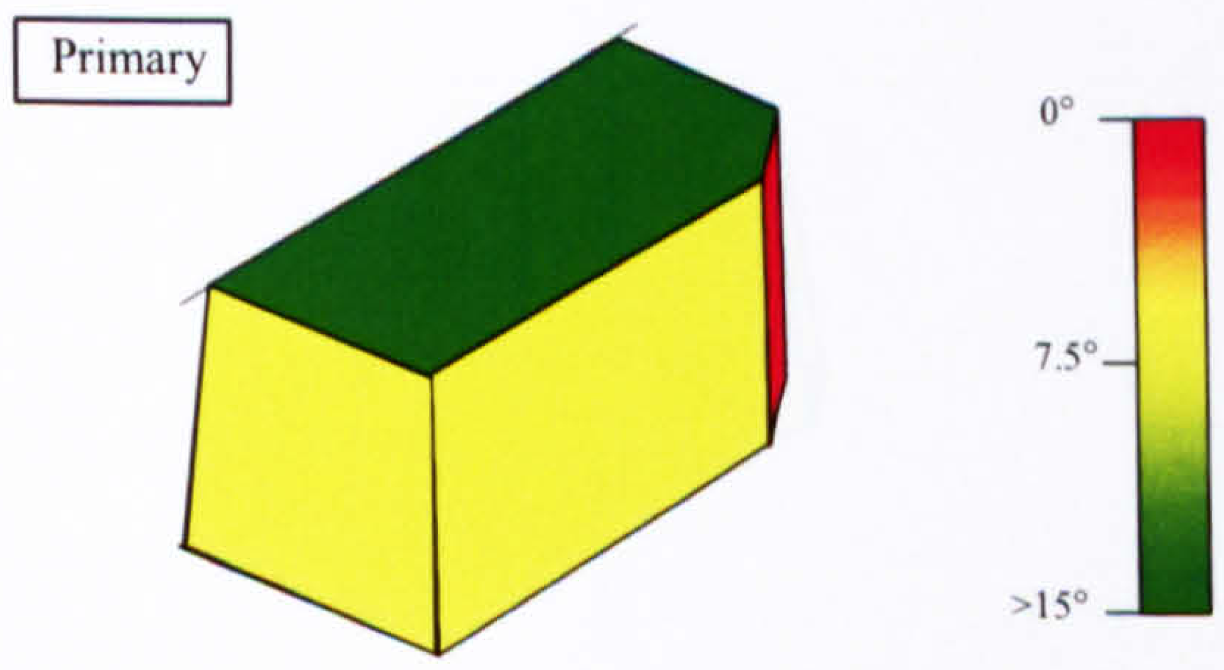
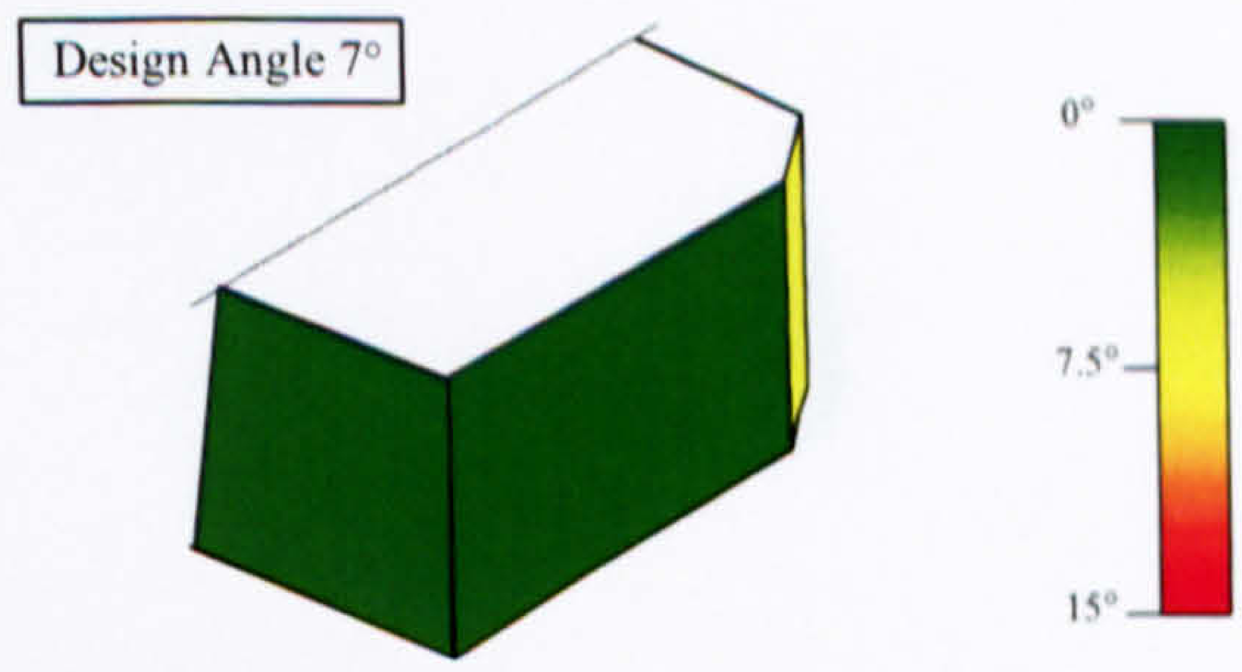
Results from the Geometric Analysis

a) Primary Reflections	b) Design Angle Returns Chosen design angle = 7°
	

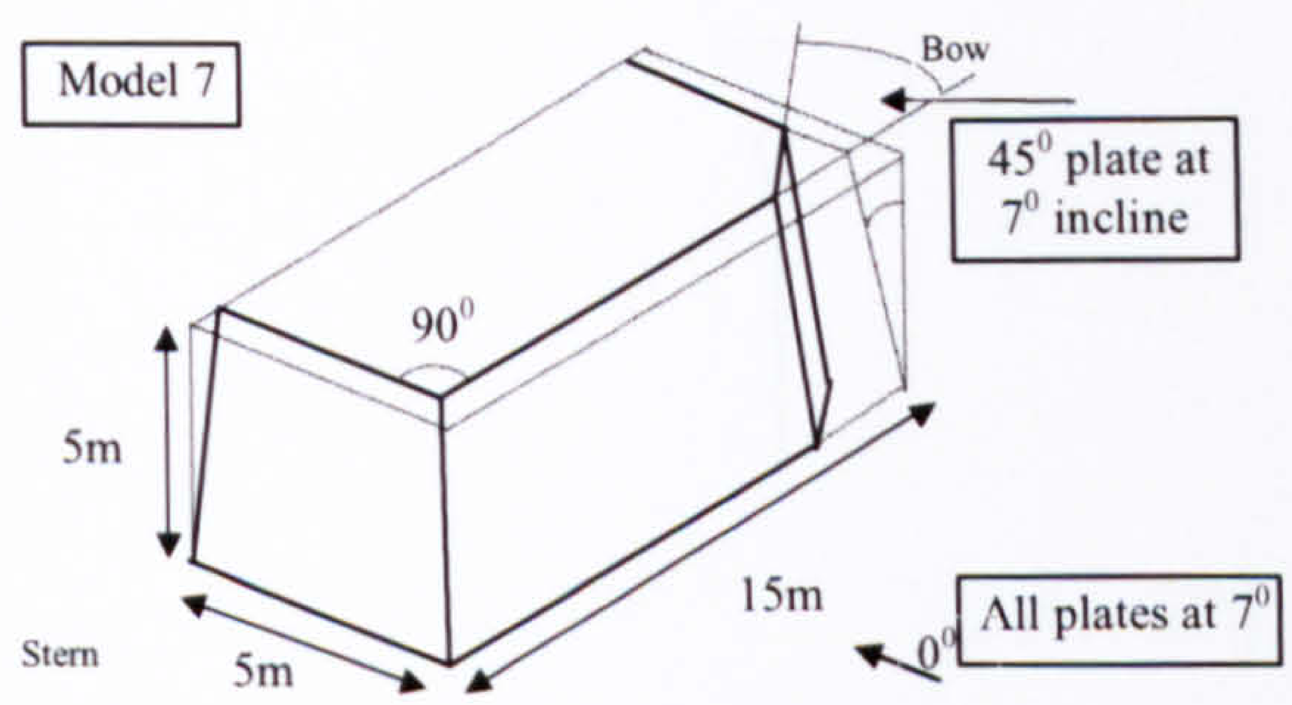
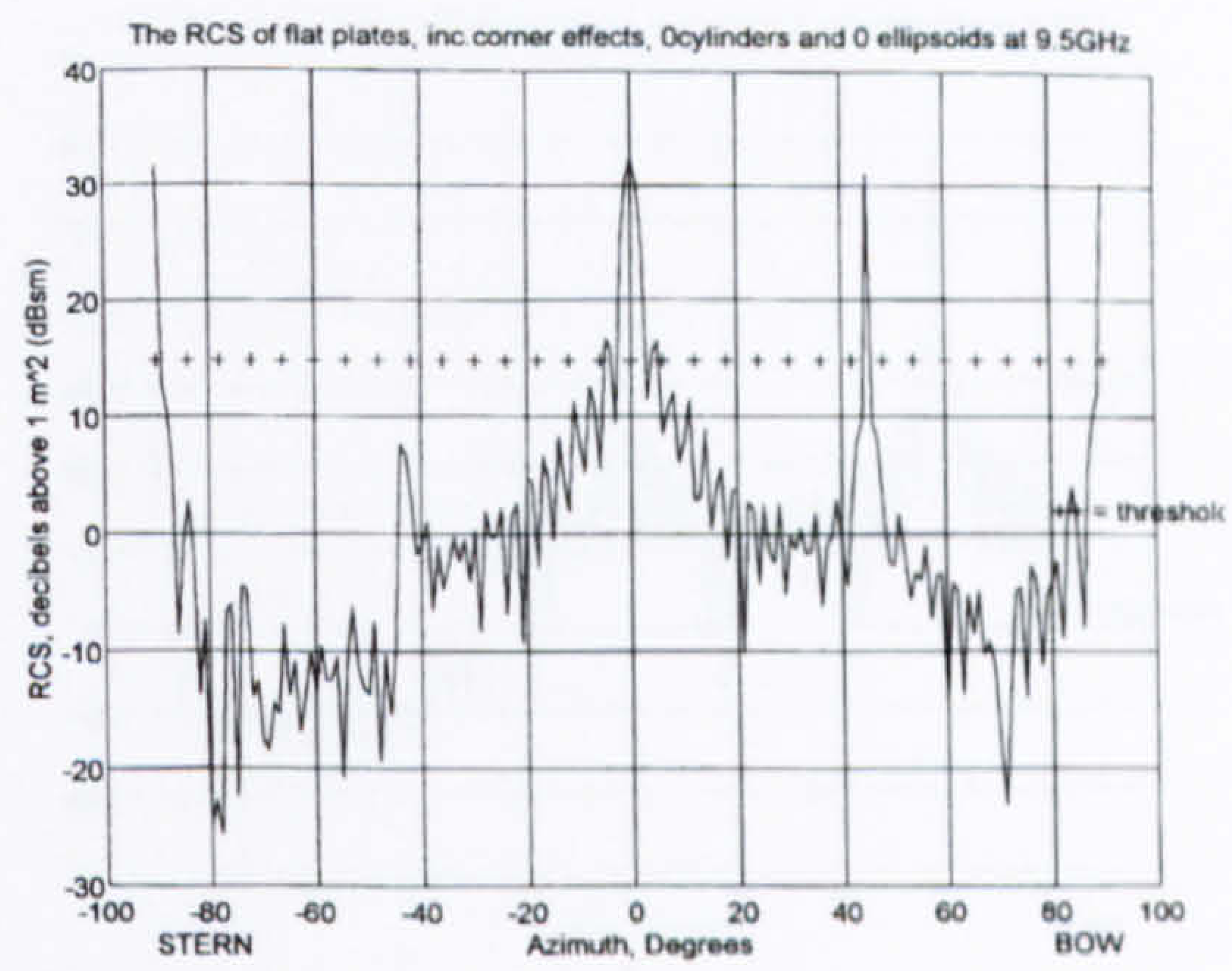
Model 6 : Box with chamfer at 45° with 0° incline, 3 plates at 7° incline

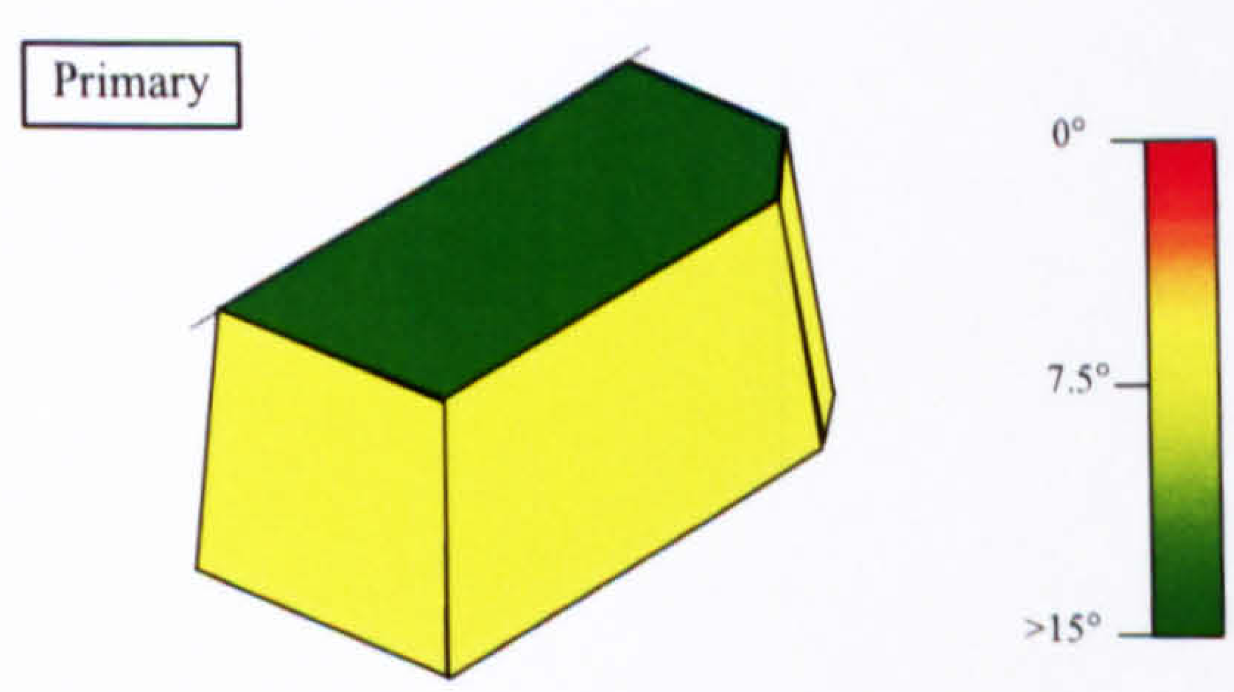
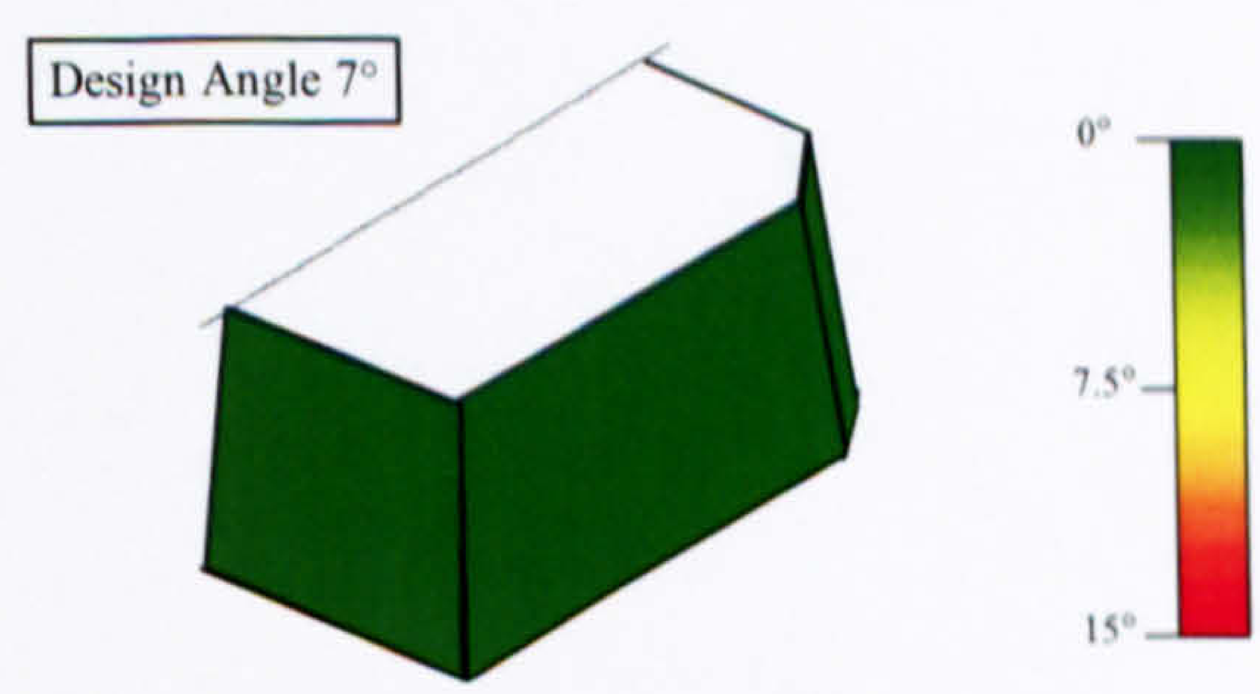
Model Definition	Results from SIRCS Analysis
	

Results from the Geometric Analysis

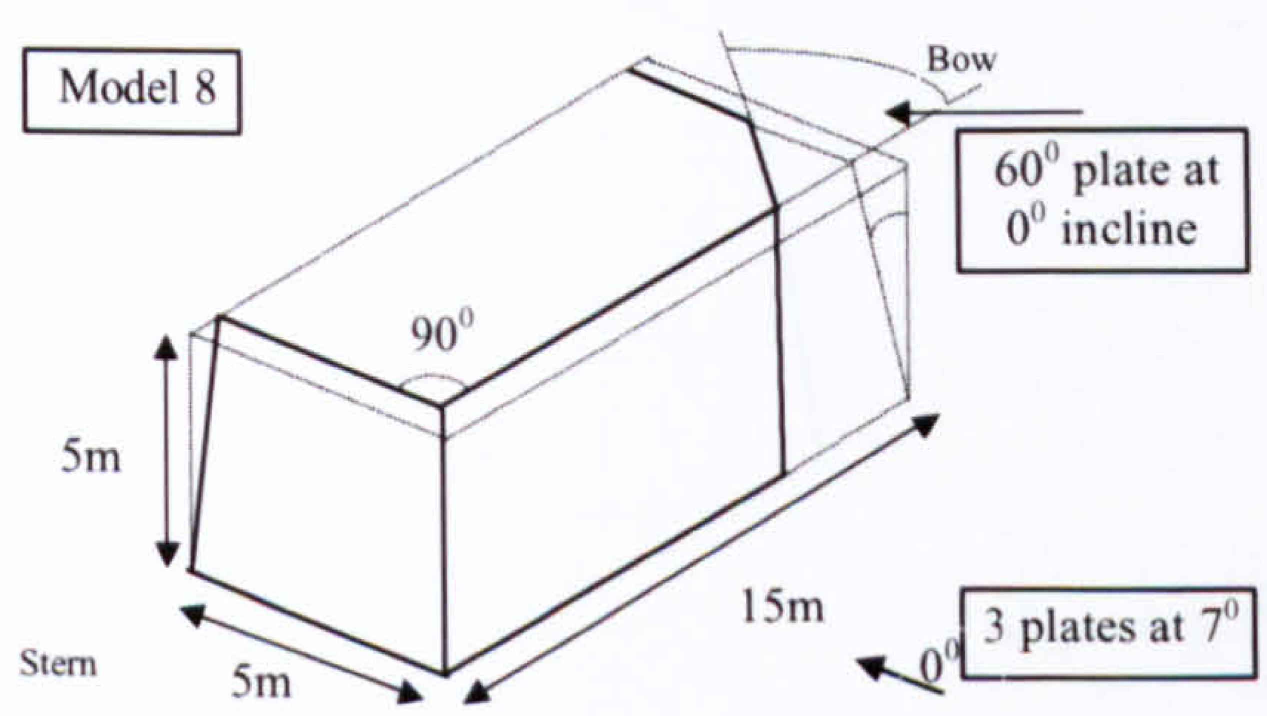
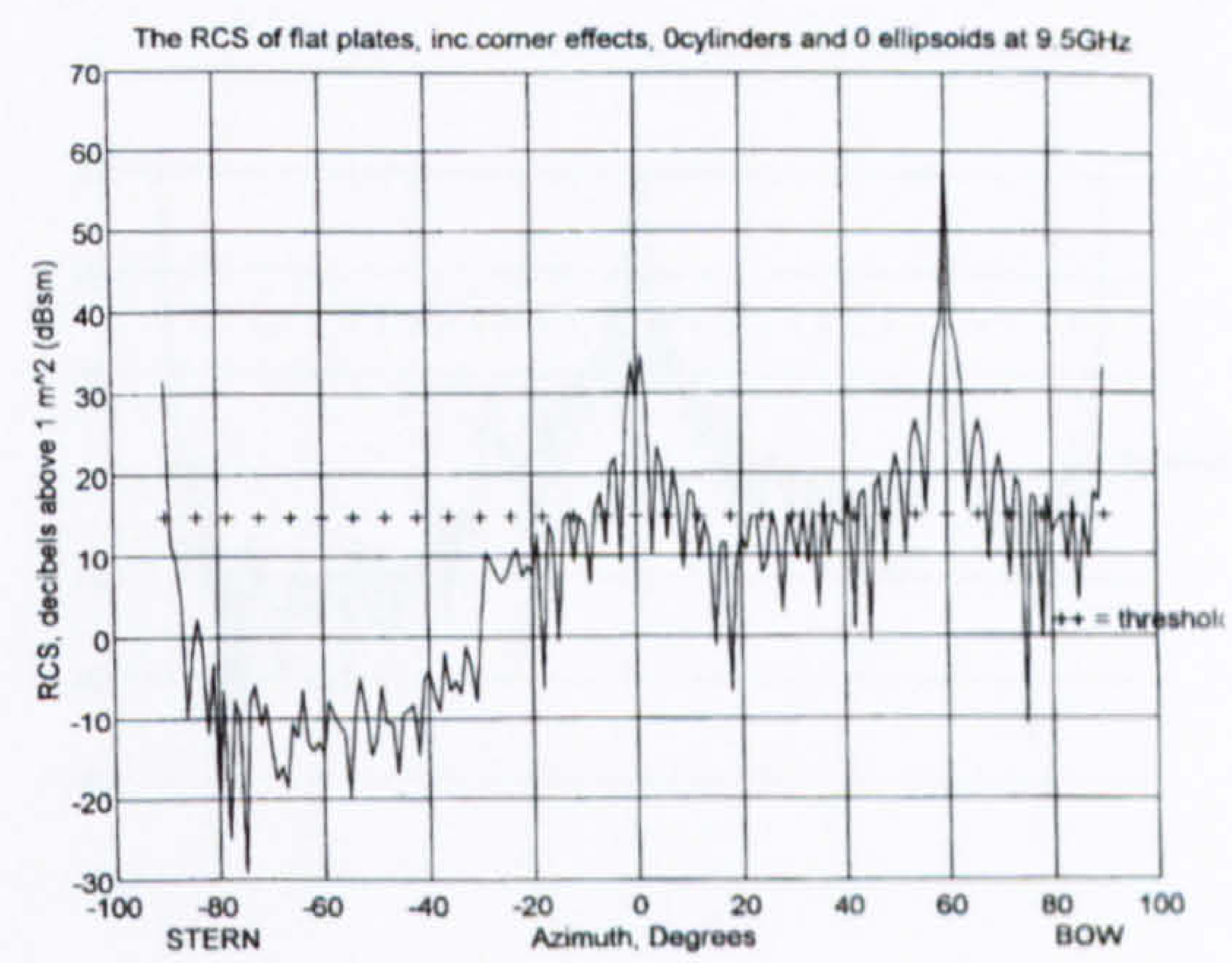
a) Primary Reflections	b) Design Angle Returns Chosen design angle = 7°
	

Model 7 : Box with chamfer at 45° with 7° incline, 3 plates at 7° incline

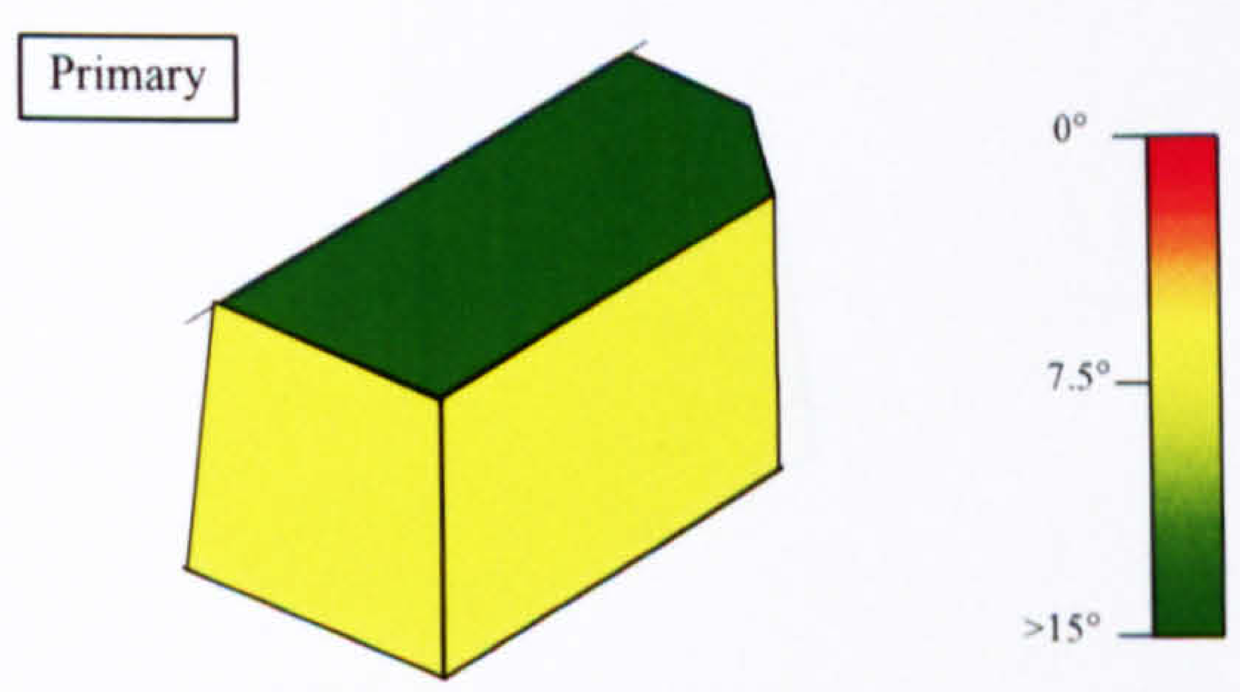
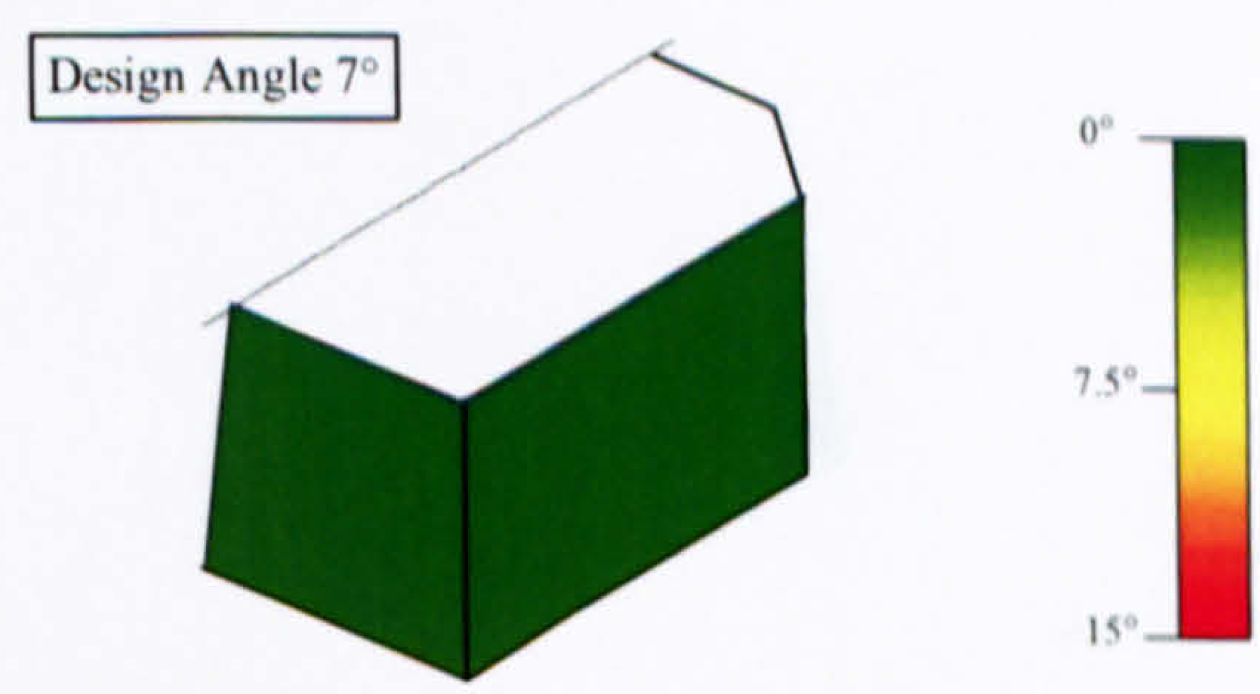
Model Definition	Results from SIRCS Analysis
	

Results from the Geometric Analysis	
a) Primary Reflections	b) Design Angle Returns Chosen design angle = 7°
	

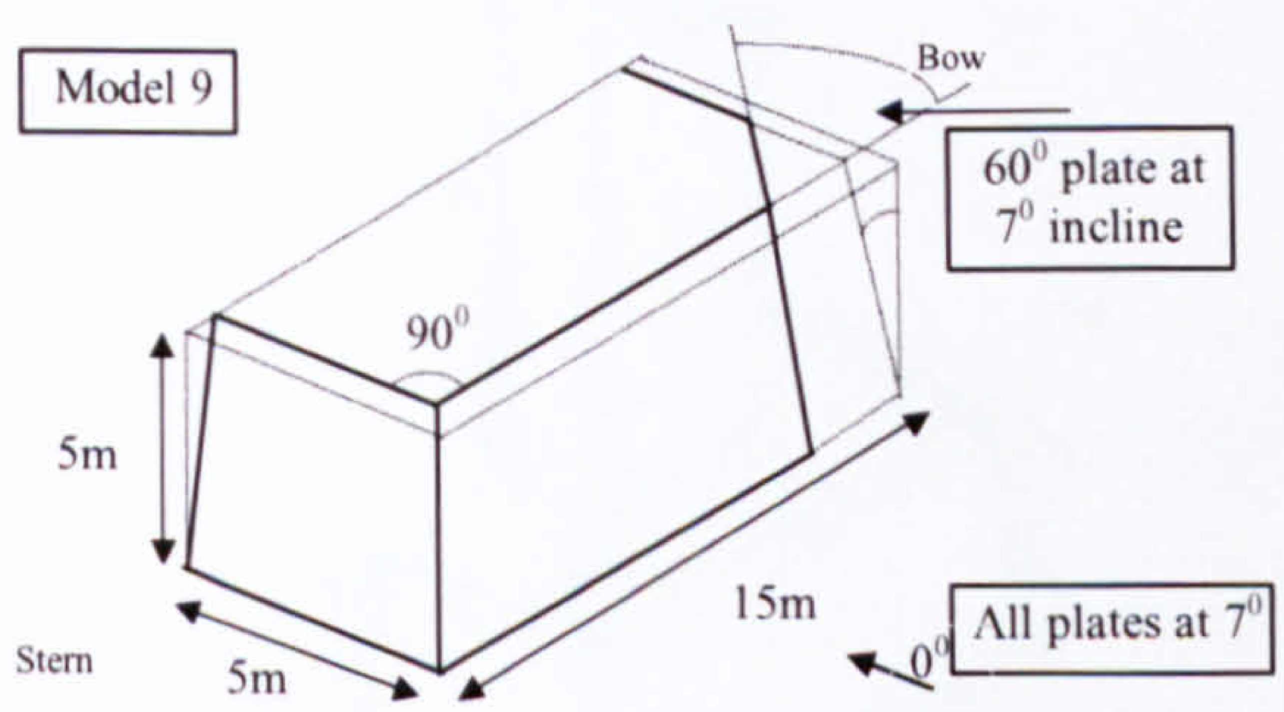
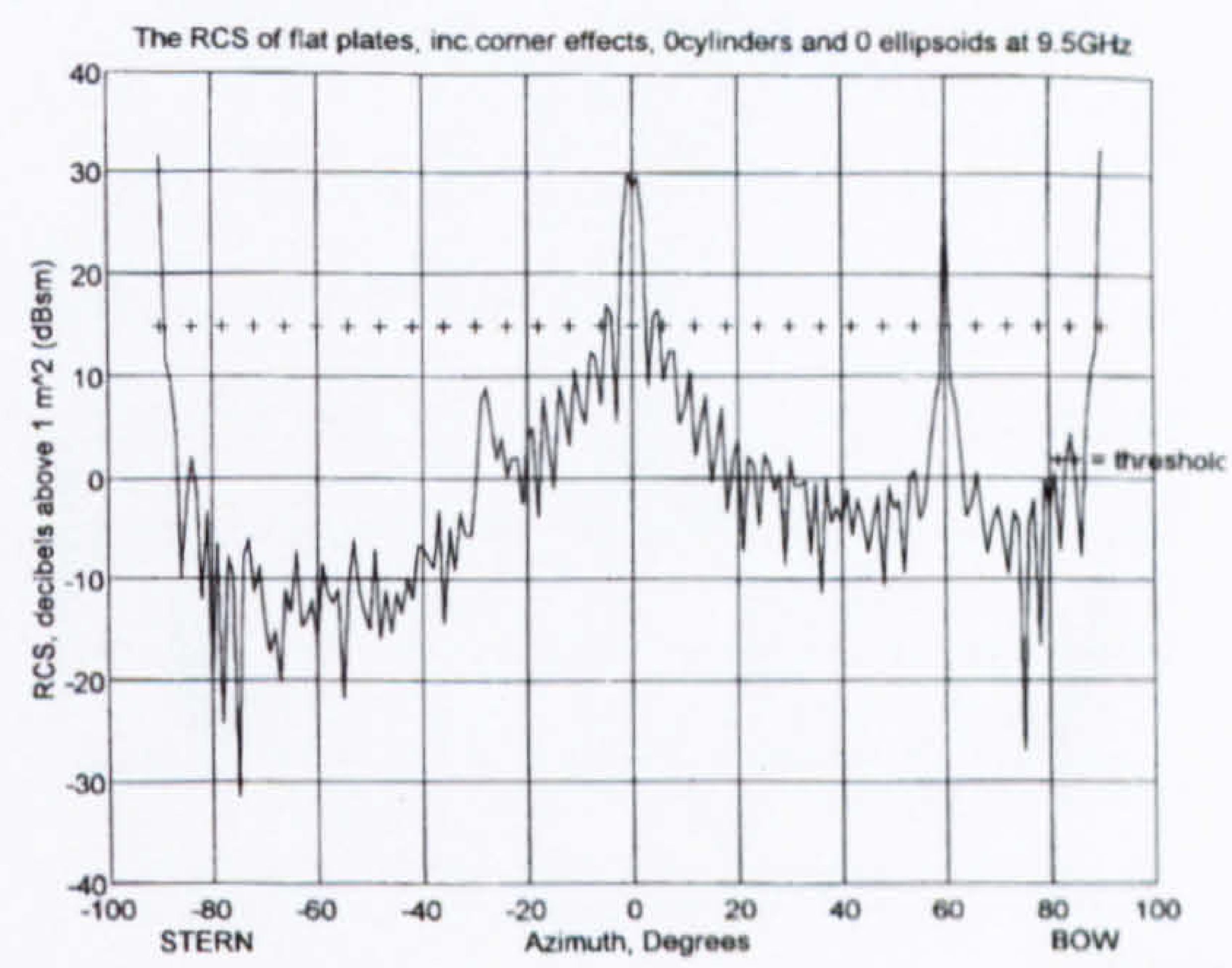
Model 8 : Box with chamfer at 60° with 0° incline, 3 plates at 7° incline

Model Definition	Results from SIRCS Analysis
	

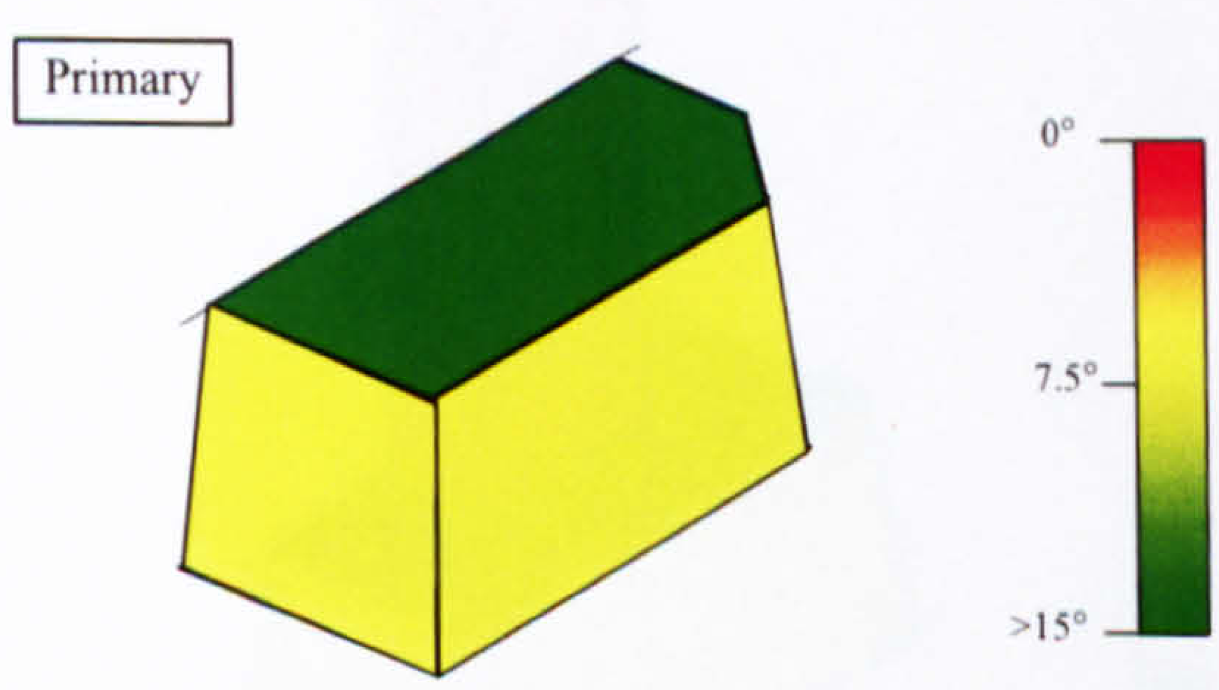
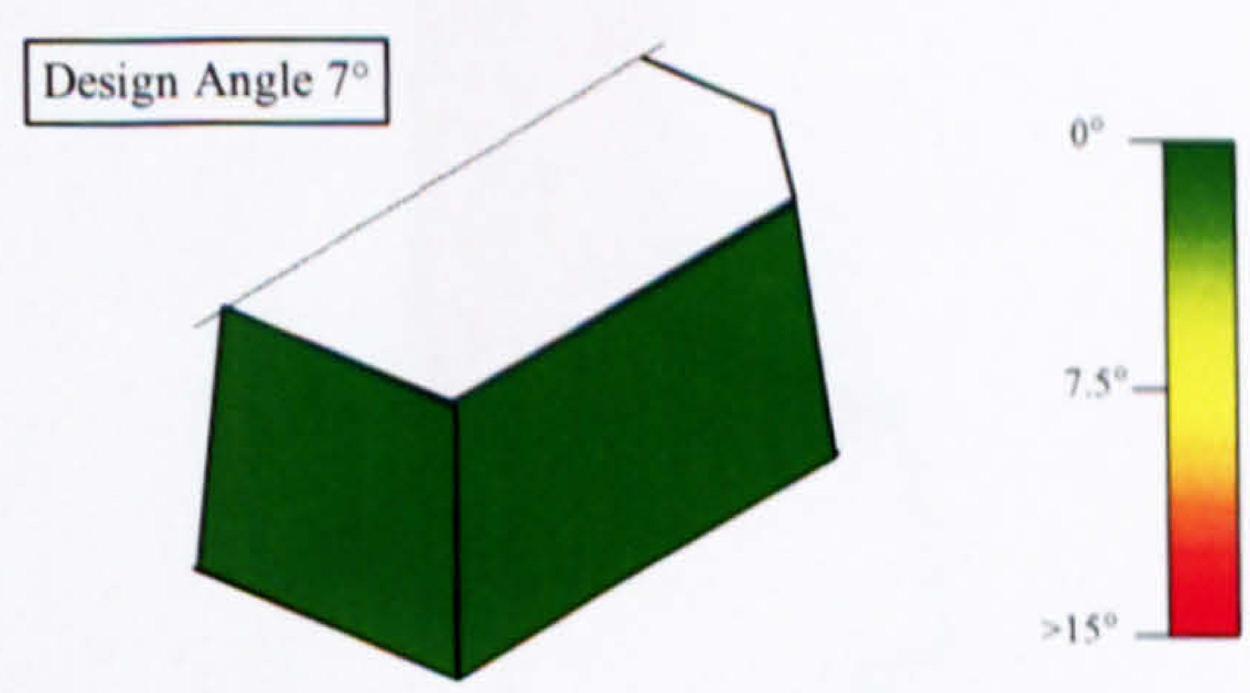
Results from the Geometric Analysis

a) Primary Reflections	b) Design Angle Returns Chosen design angle = 0°
	

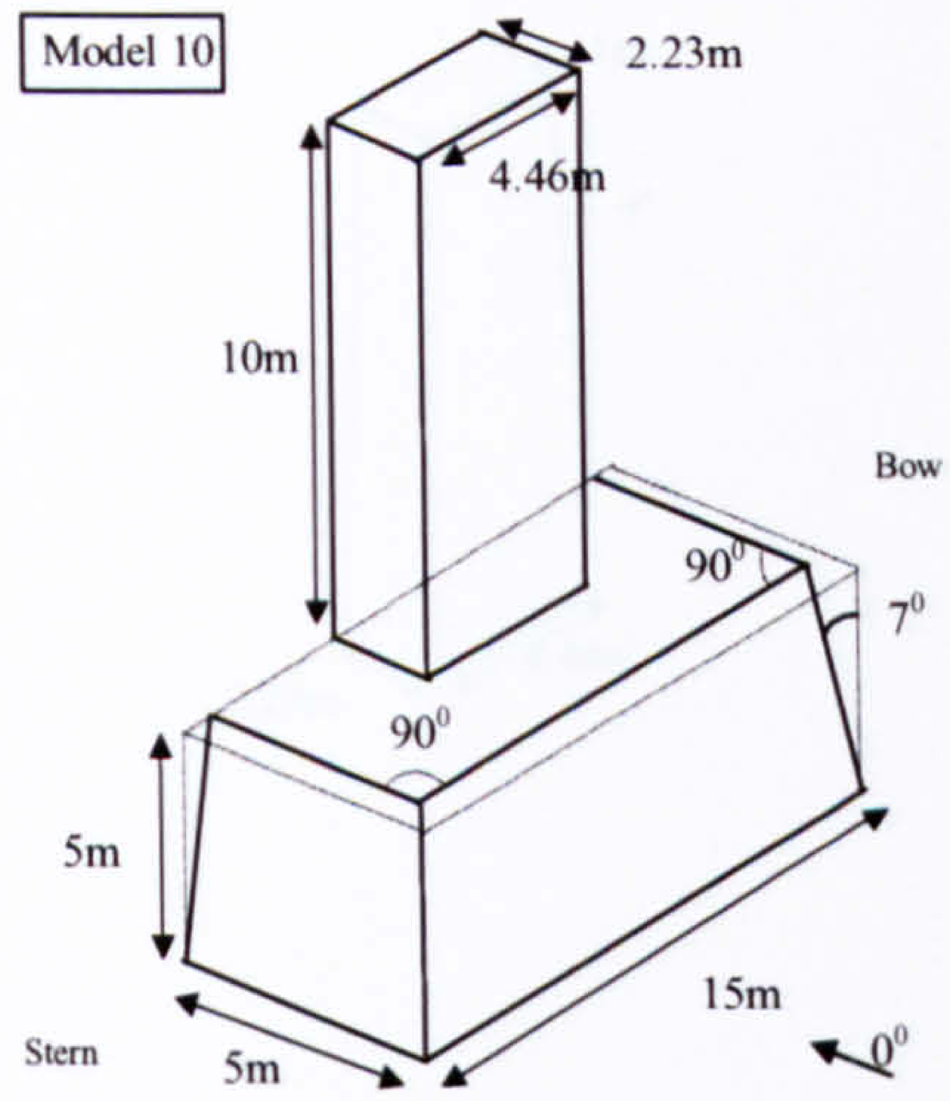
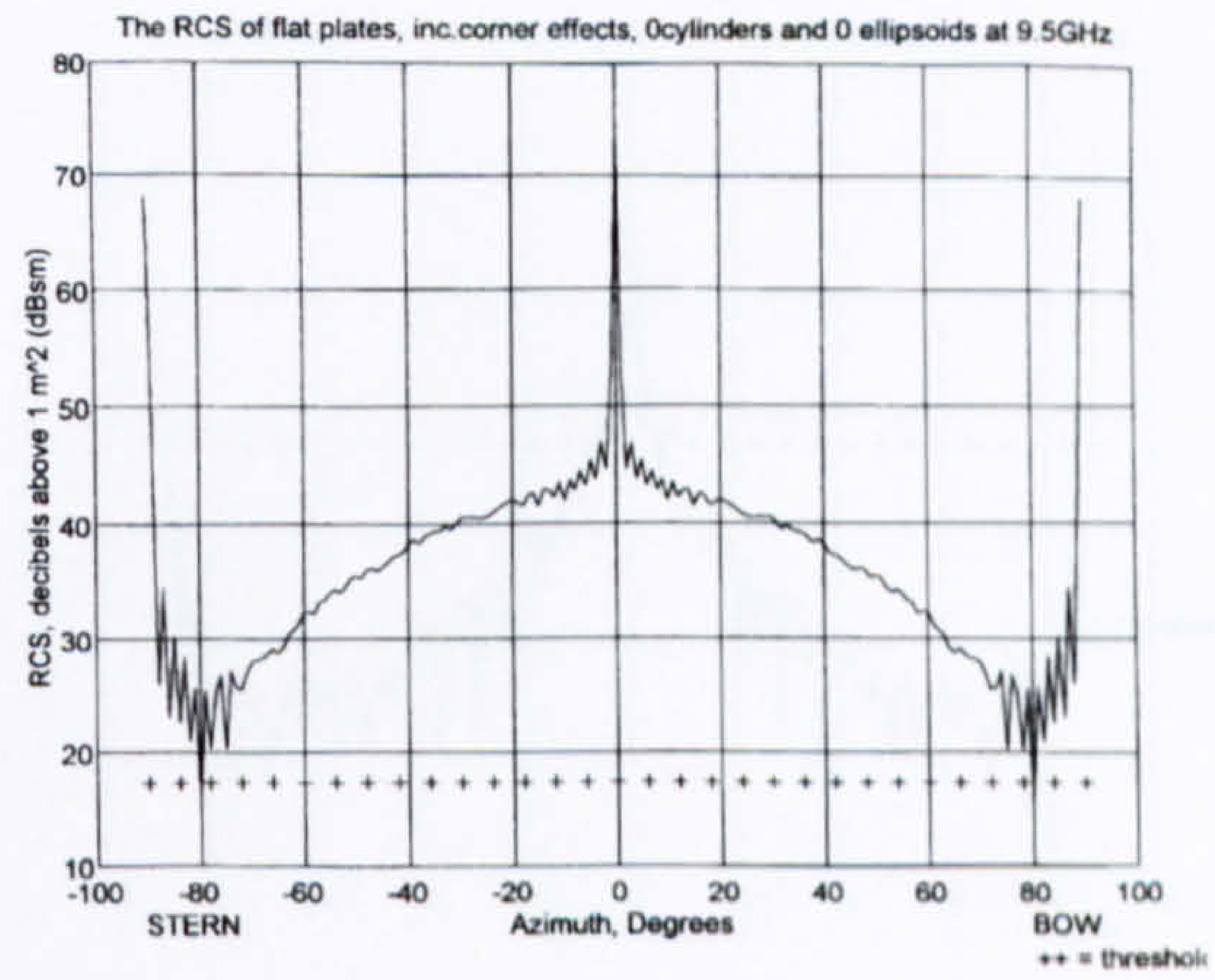
Model 9 : Box with chamfer at 60° with 7° incline, 3 plates at 7° incline

Model Definition	Results from SIRCS Analysis
	

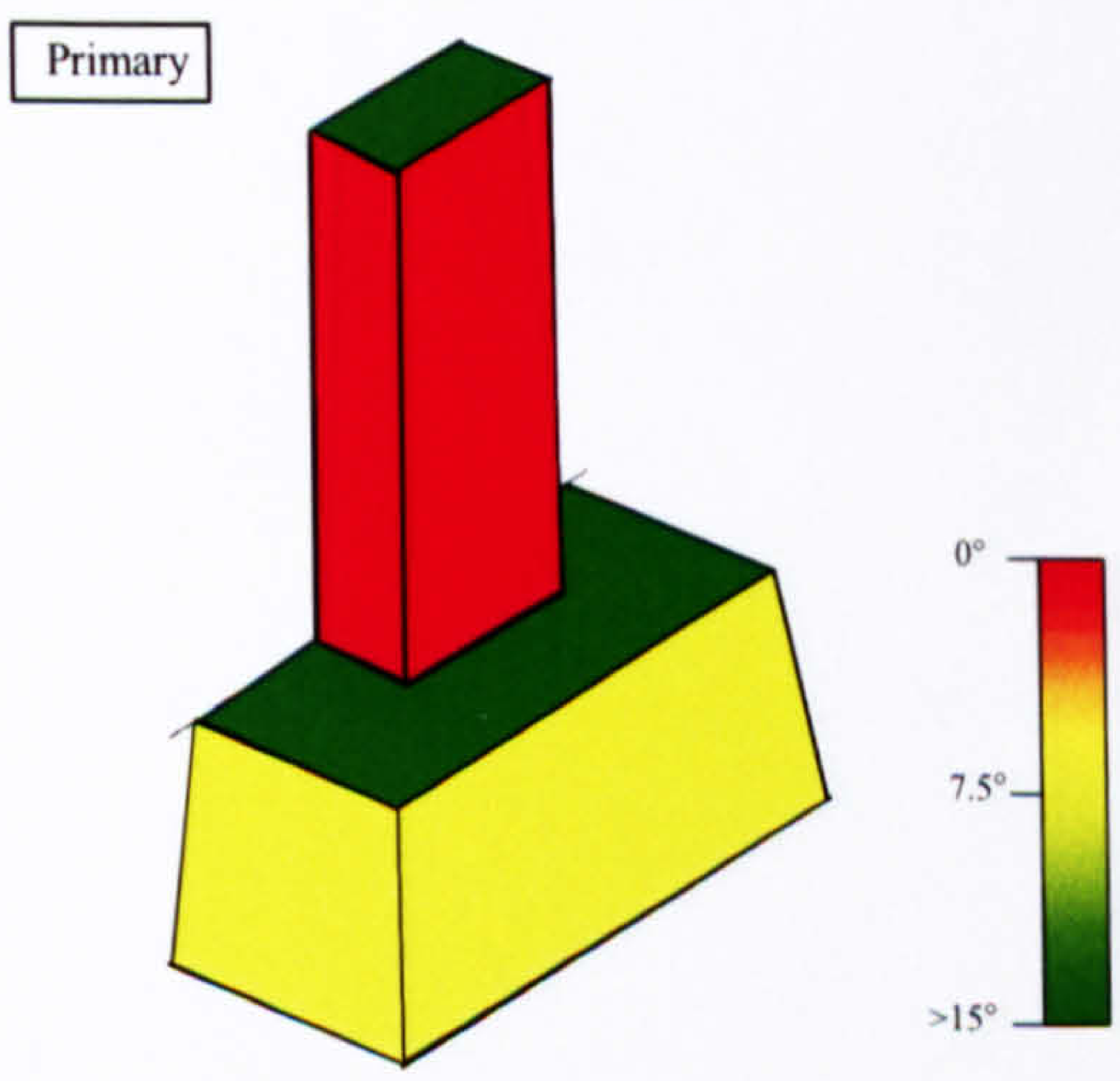
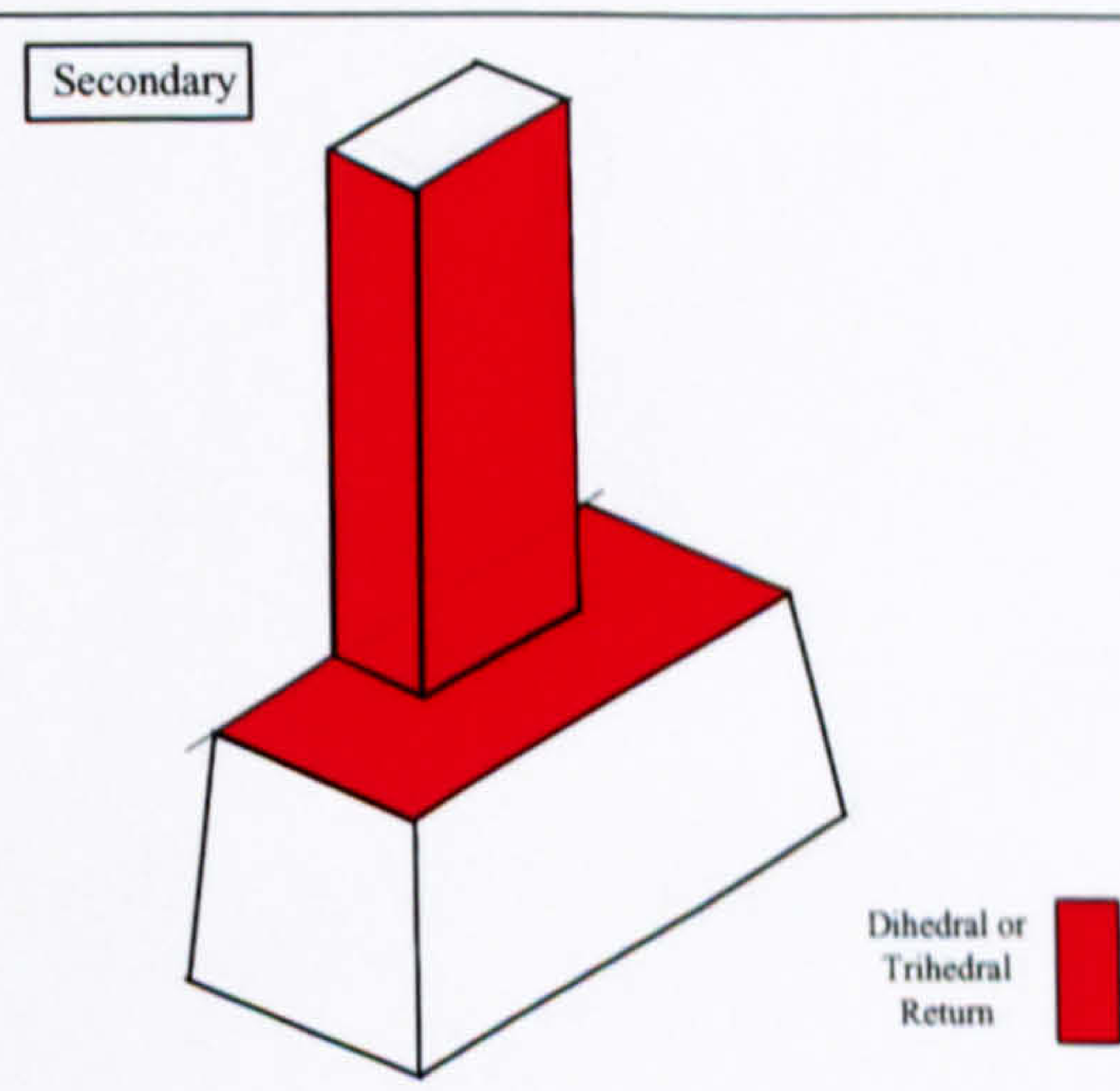
Results from the Geometric Analysis

a) Primary Reflections	b) Design Angle Returns Chosen design angle = 0°
	

Model 10 : Base with 7° incline with square mast at 0° incline

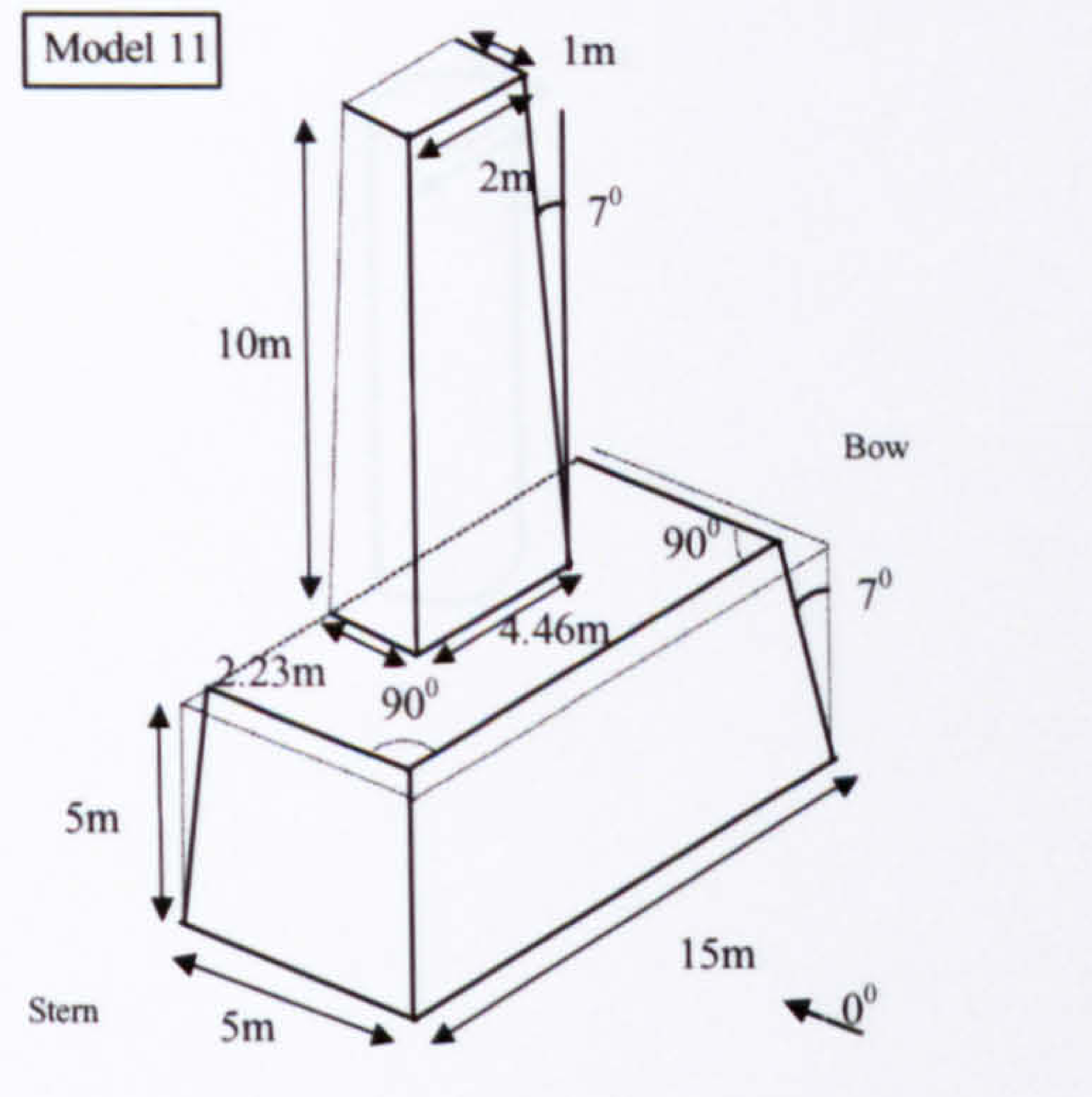
Model Definition	Results from SIRCS Analysis
	

Results from the Geometric Analysis

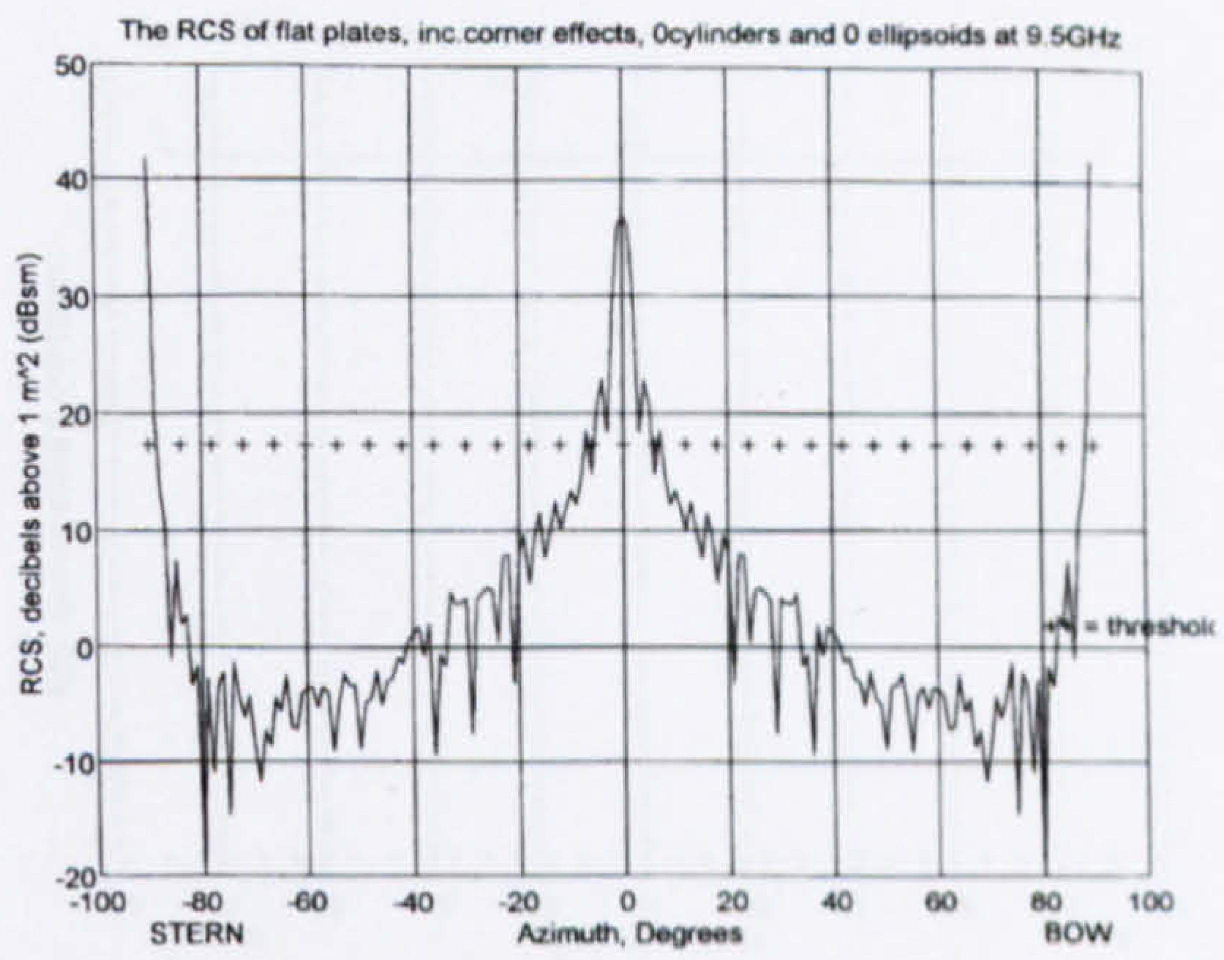
a) Primary Reflections	b) Secondary Reflections
	

Model 11 : Base with 7° incline with square mast at 7° incline

Model Definition

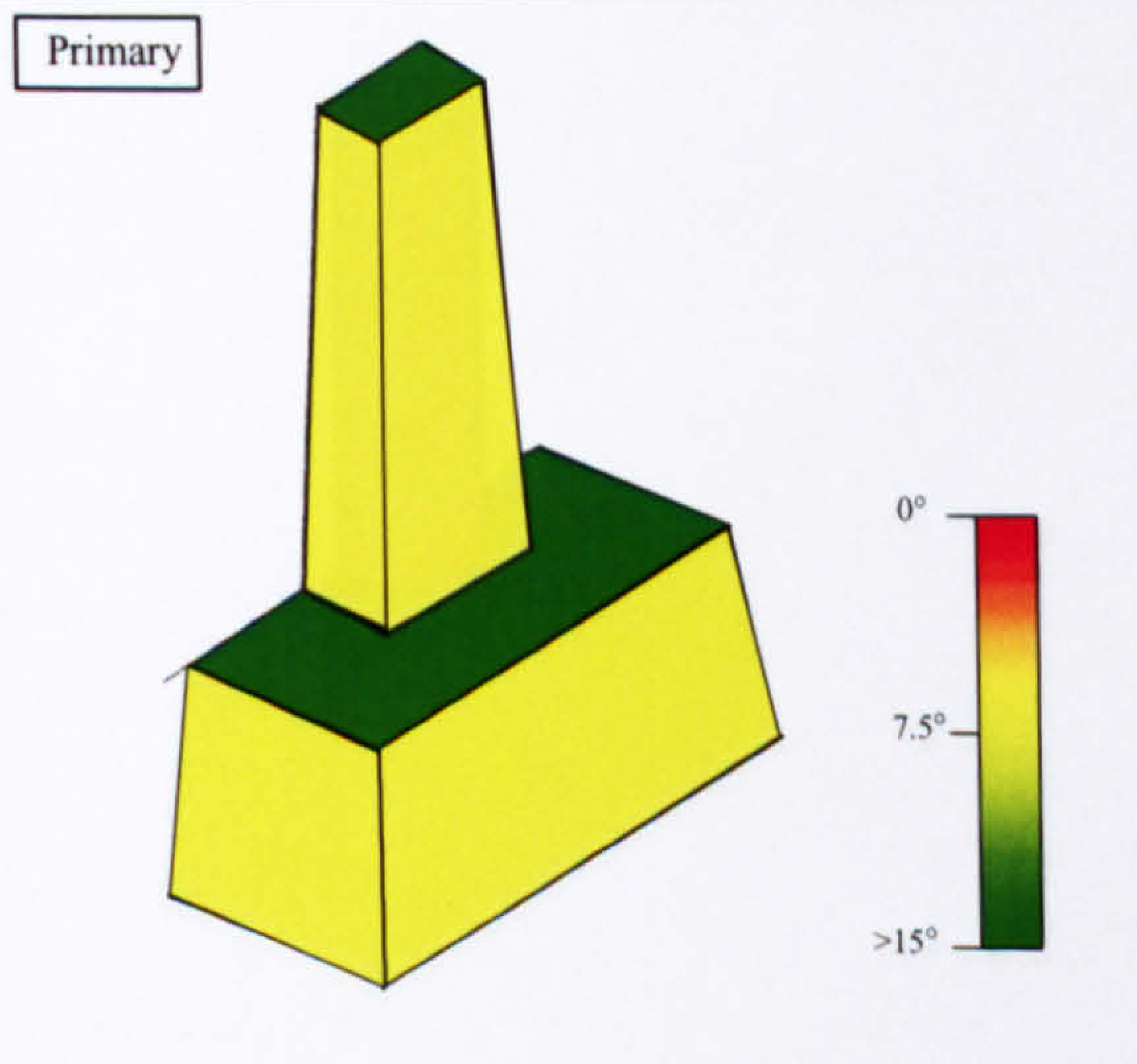


Results from SIRCS Analysis

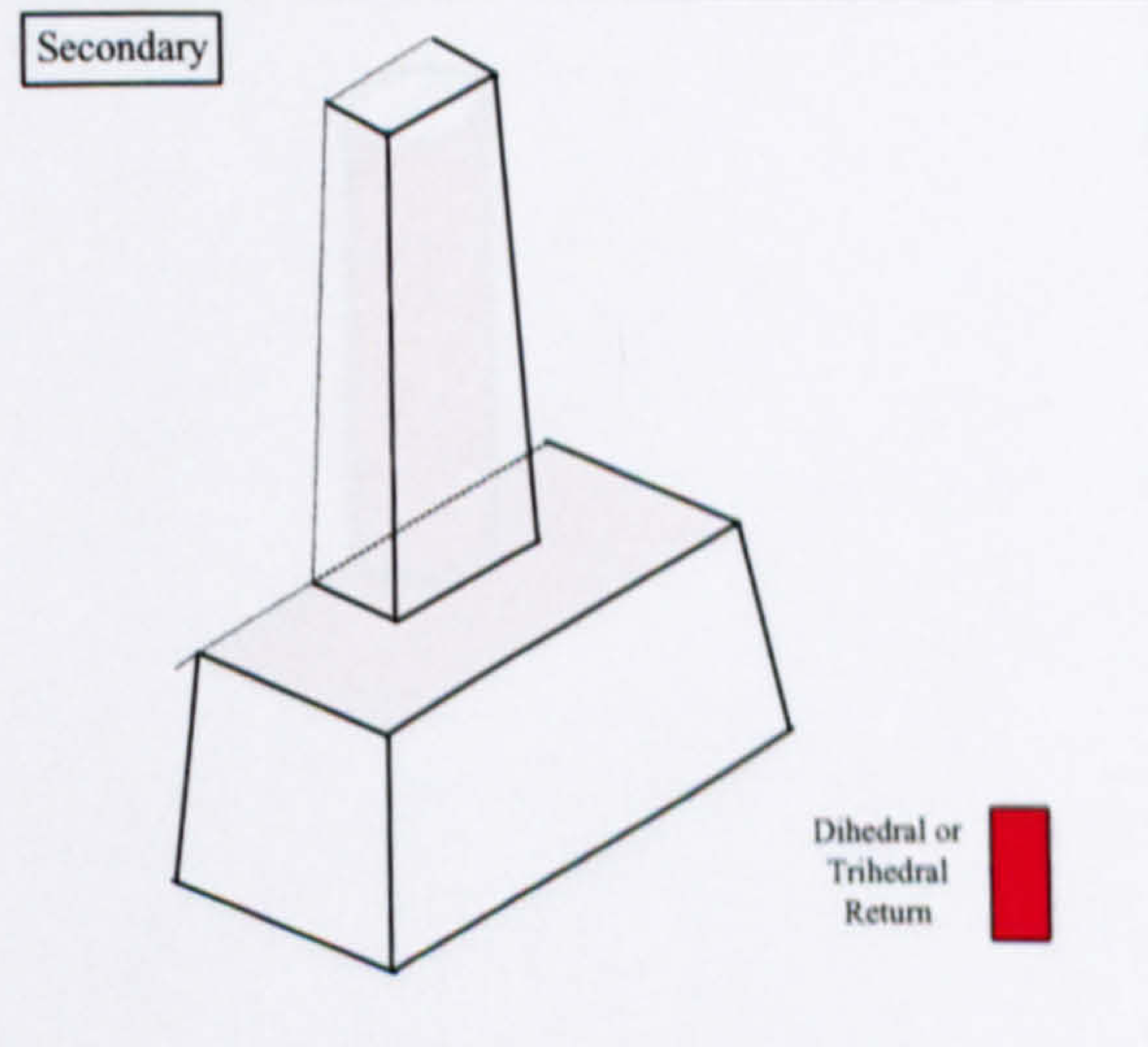


Results from the Geometric Analysis

a) Primary Reflections



b) Secondary Reflections



Model 12 : Base with 7° incline with circular mast at 0° incline

<table>
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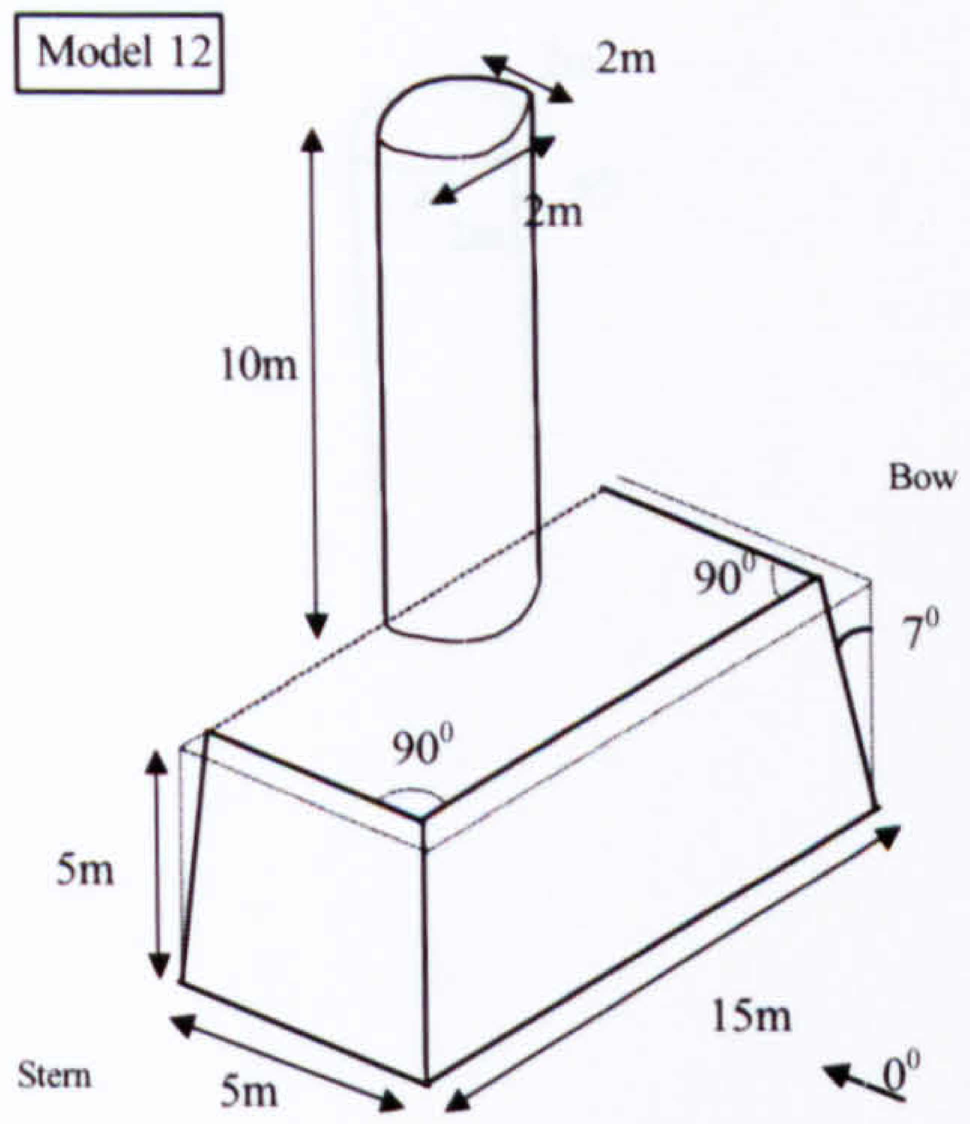
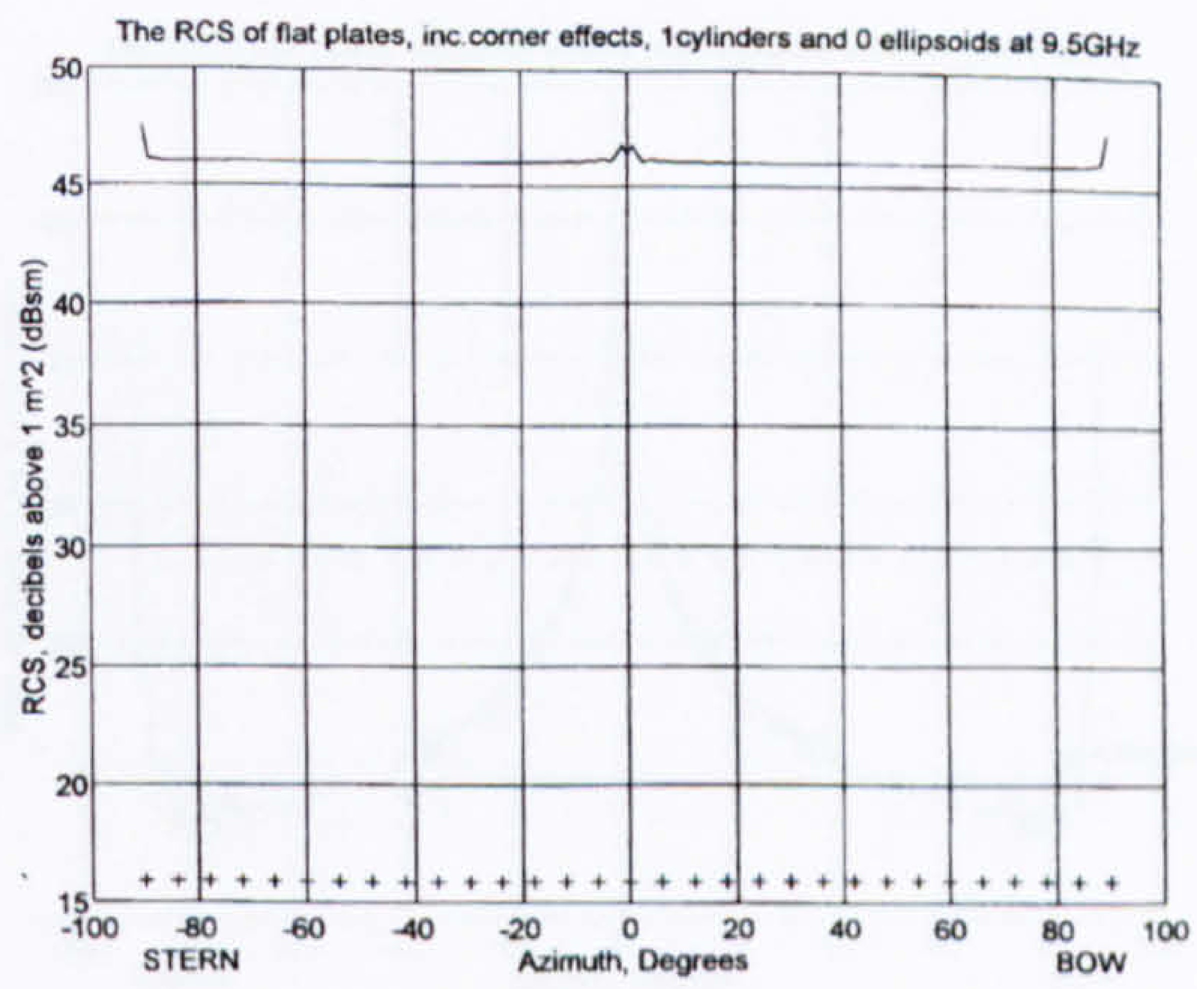
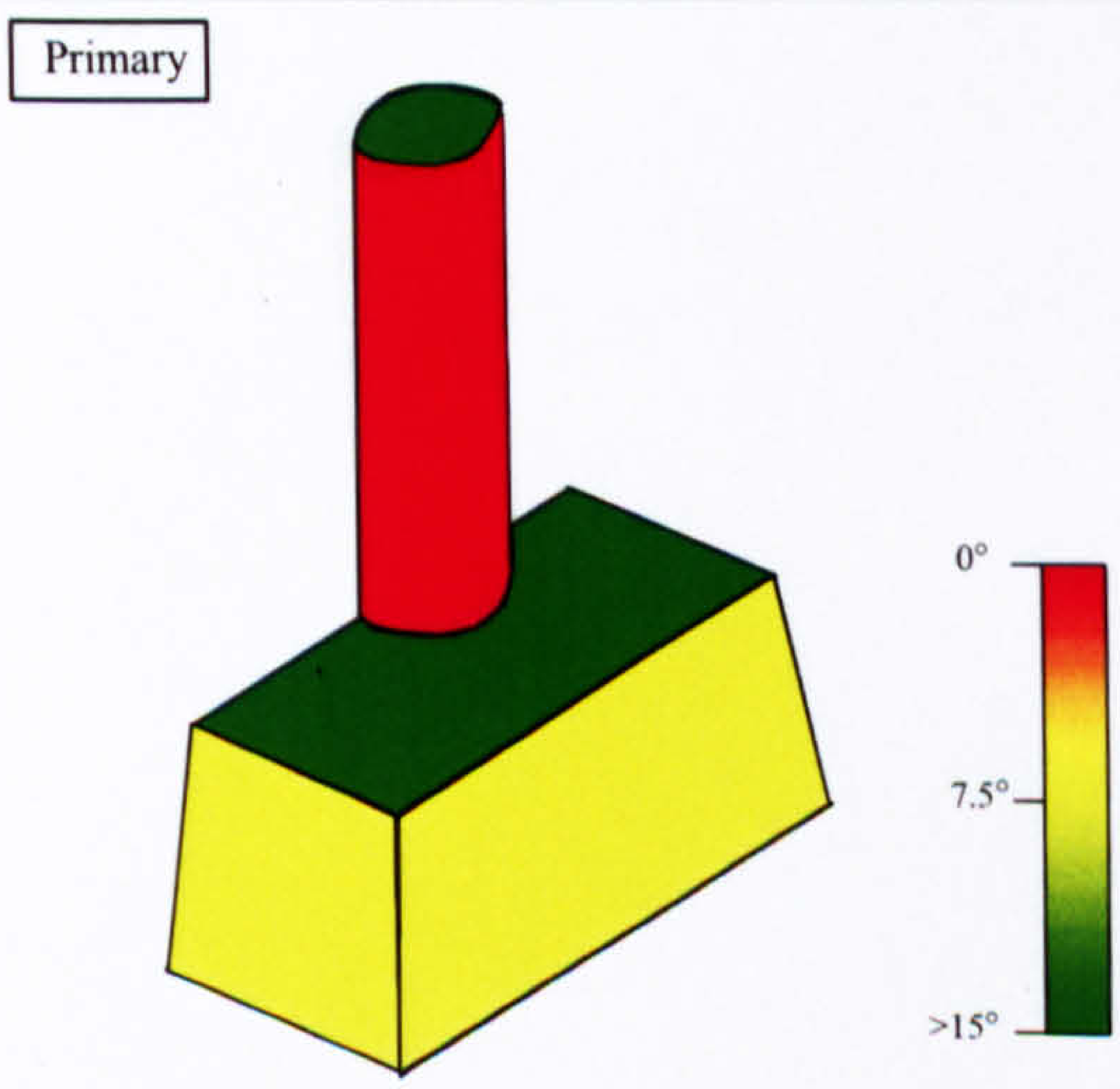
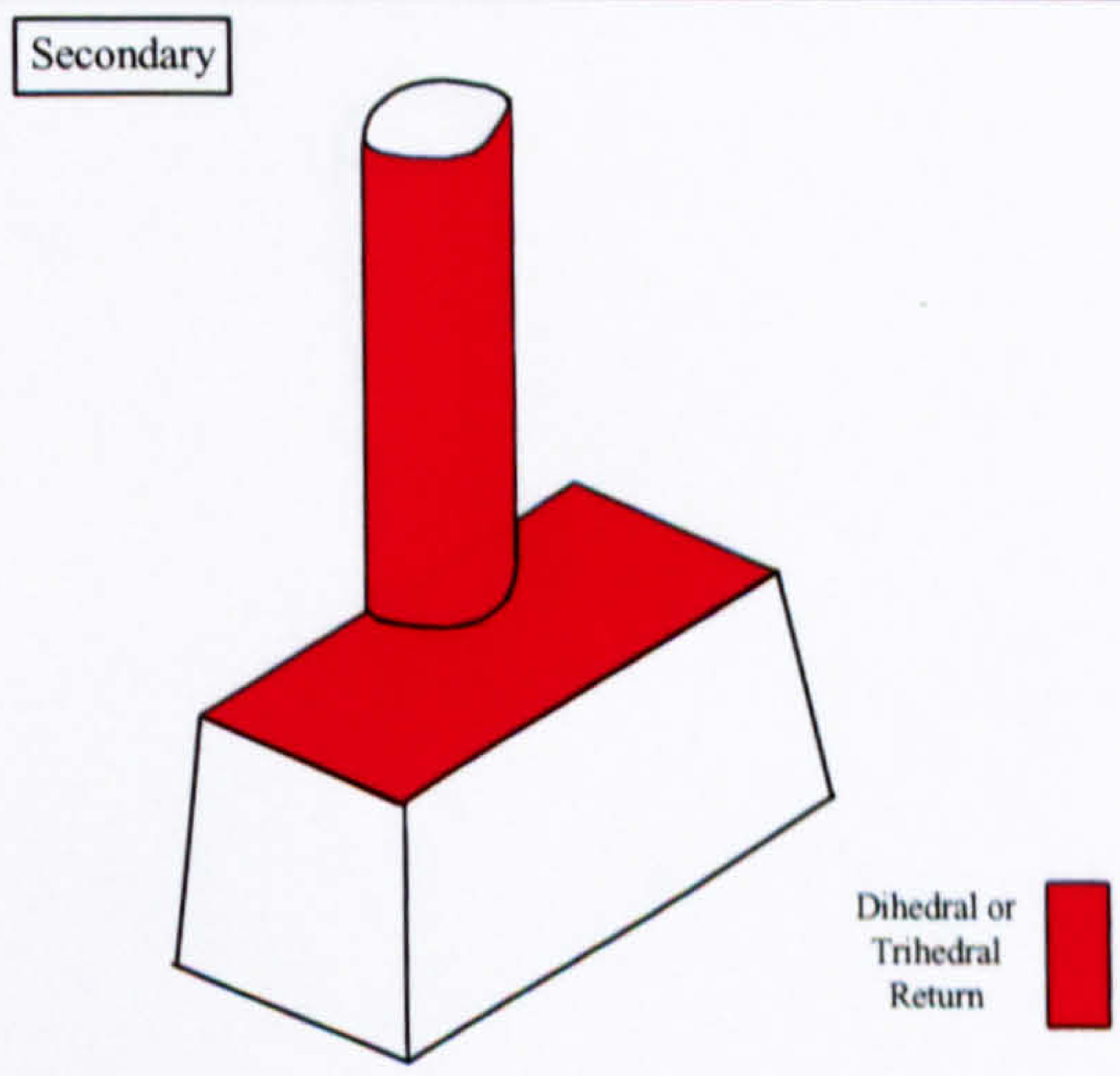
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Results from the Geometric Analysis</td></tr>
<tr><td>a) Primary Reflections</td><td>b) Secondary Reflections</td></tr>
<tr><td>
</td><td>
</td></tr>
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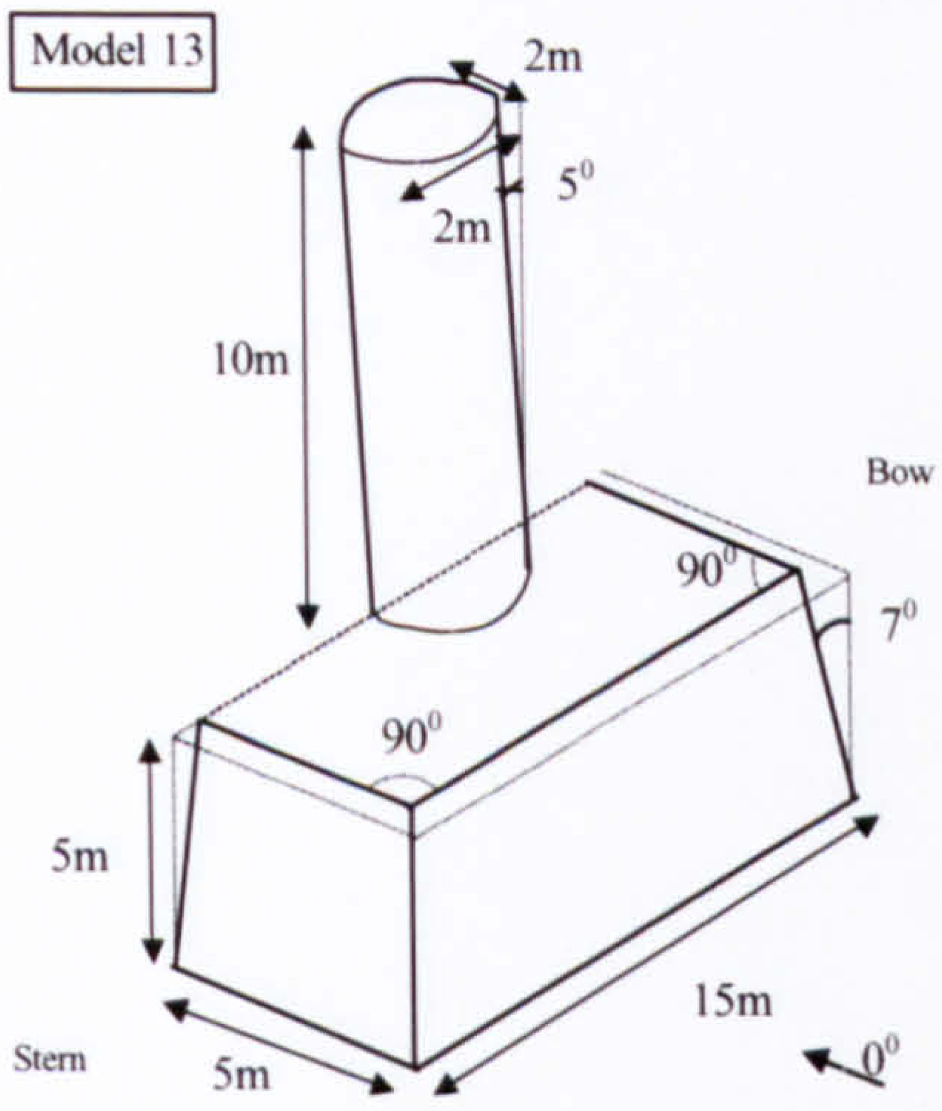
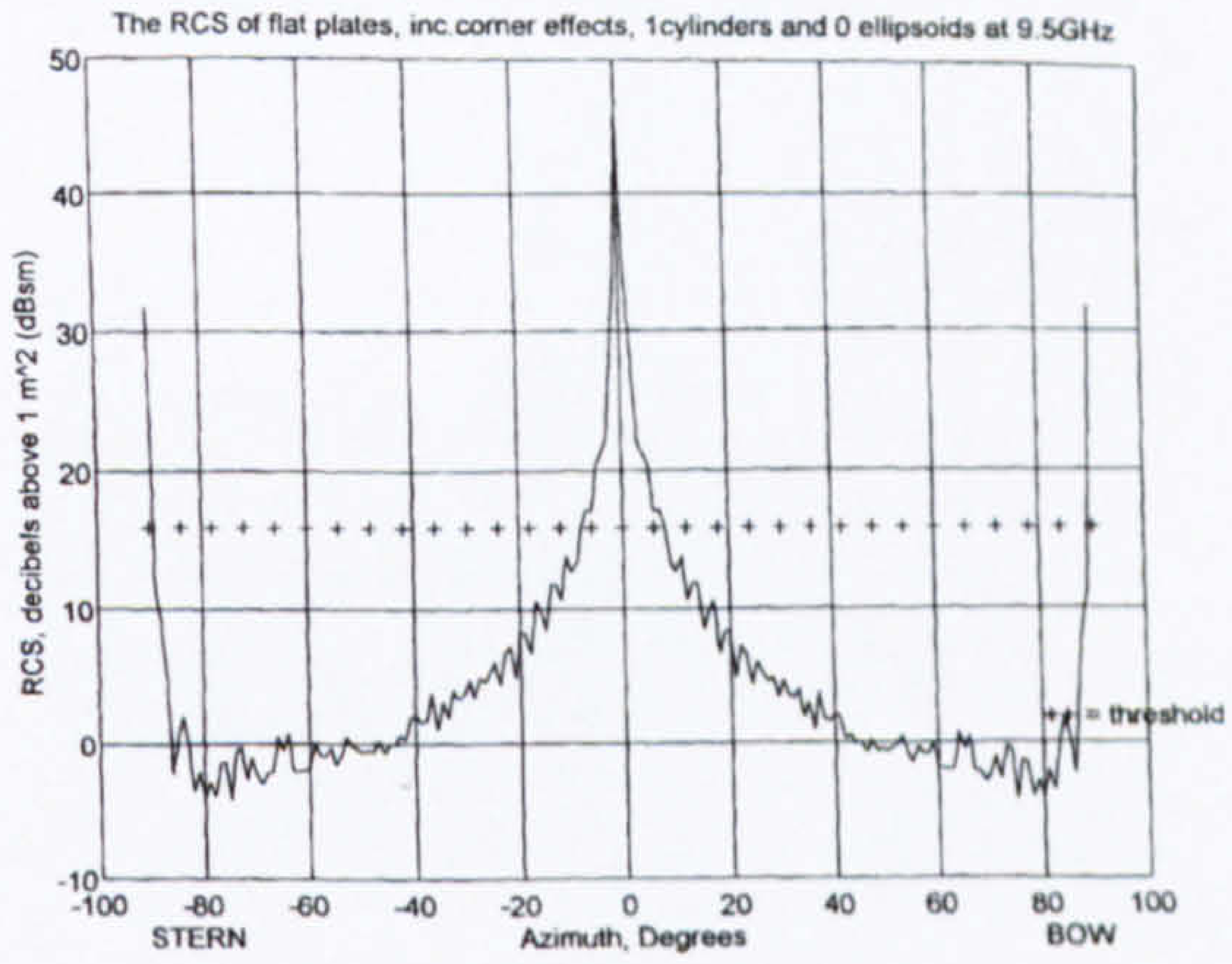
Model 13 : Base with 7° incline with circular mast at 5° incline

Model Definition

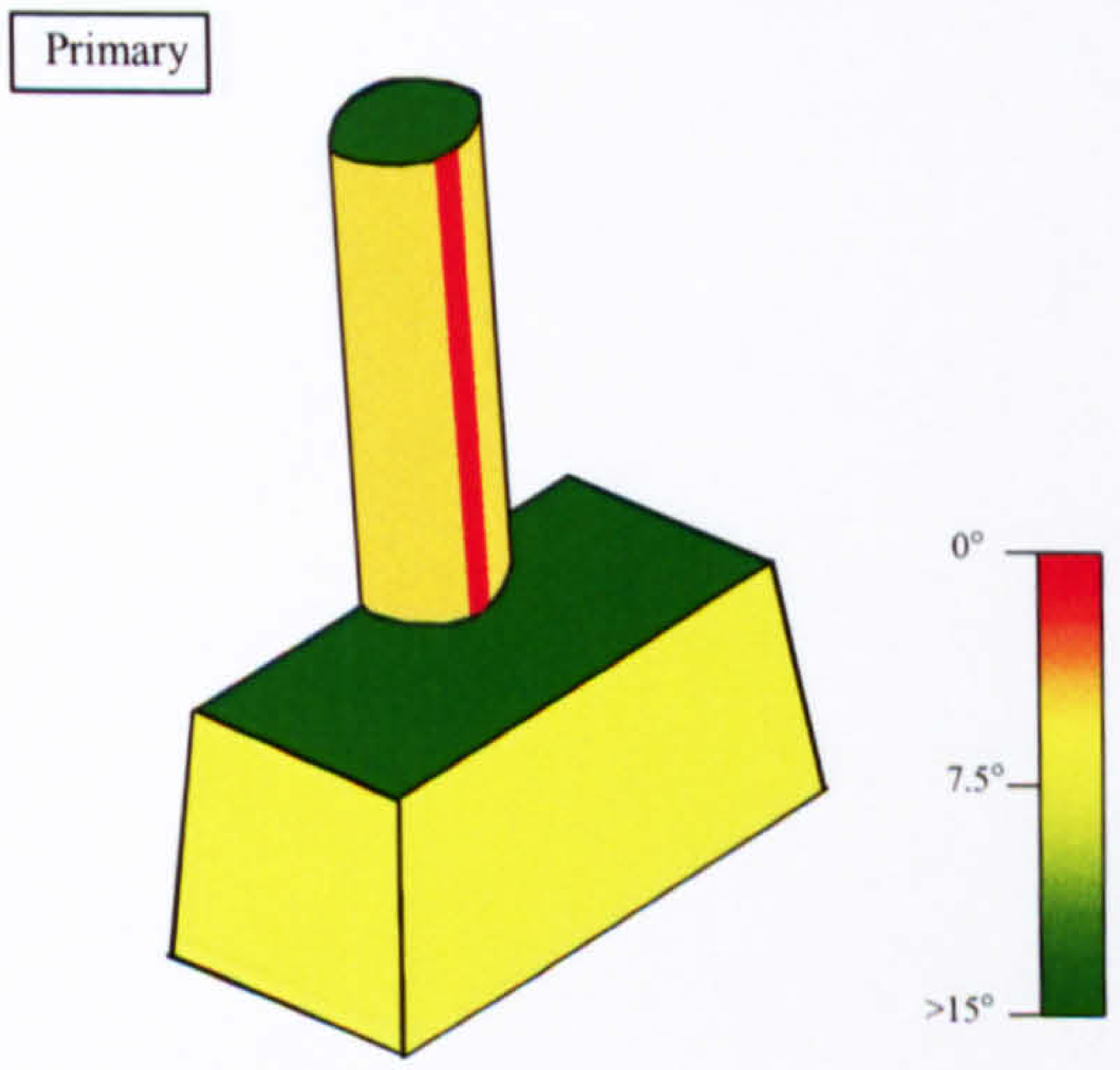


Results from SIRCS Analysis

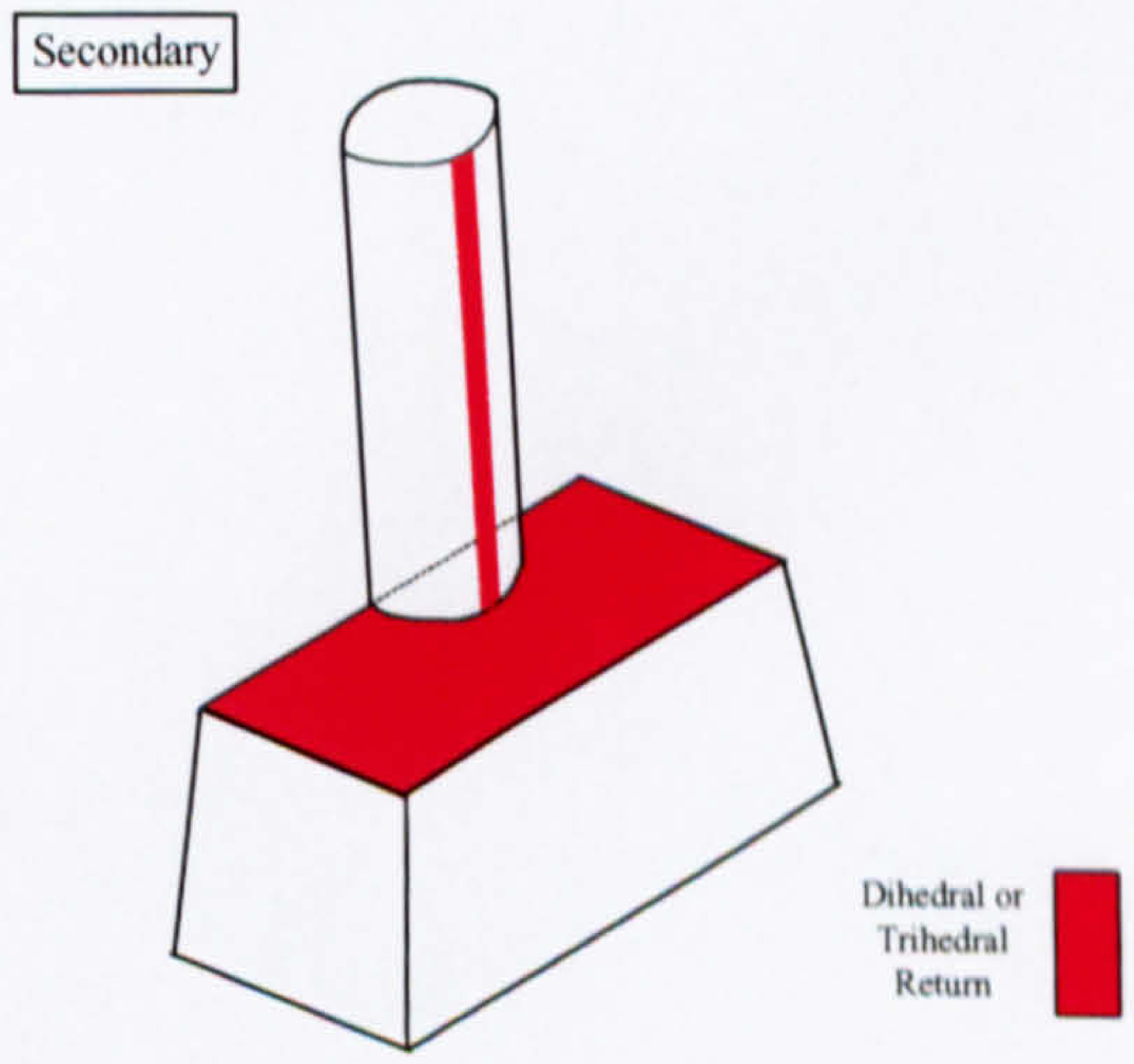


Results from the Geometric Analysis

a) Primary Reflections

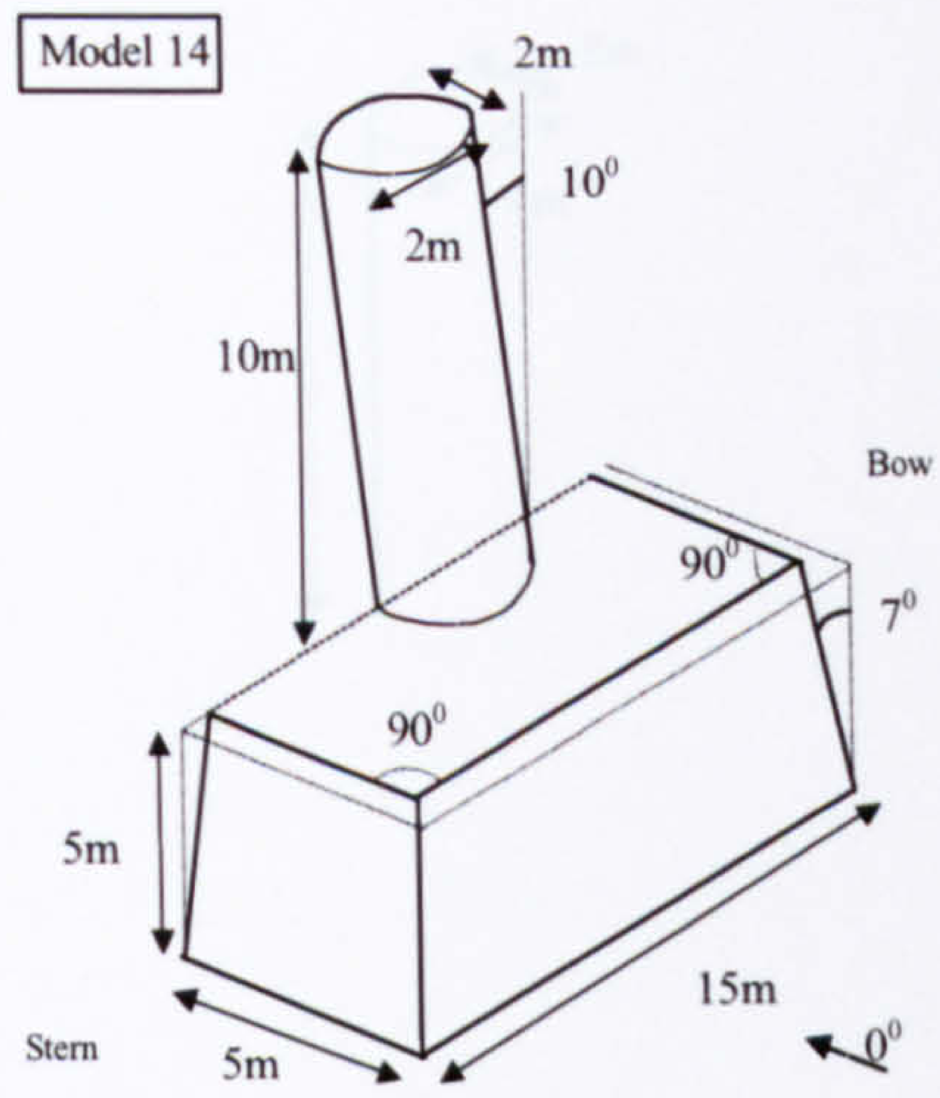
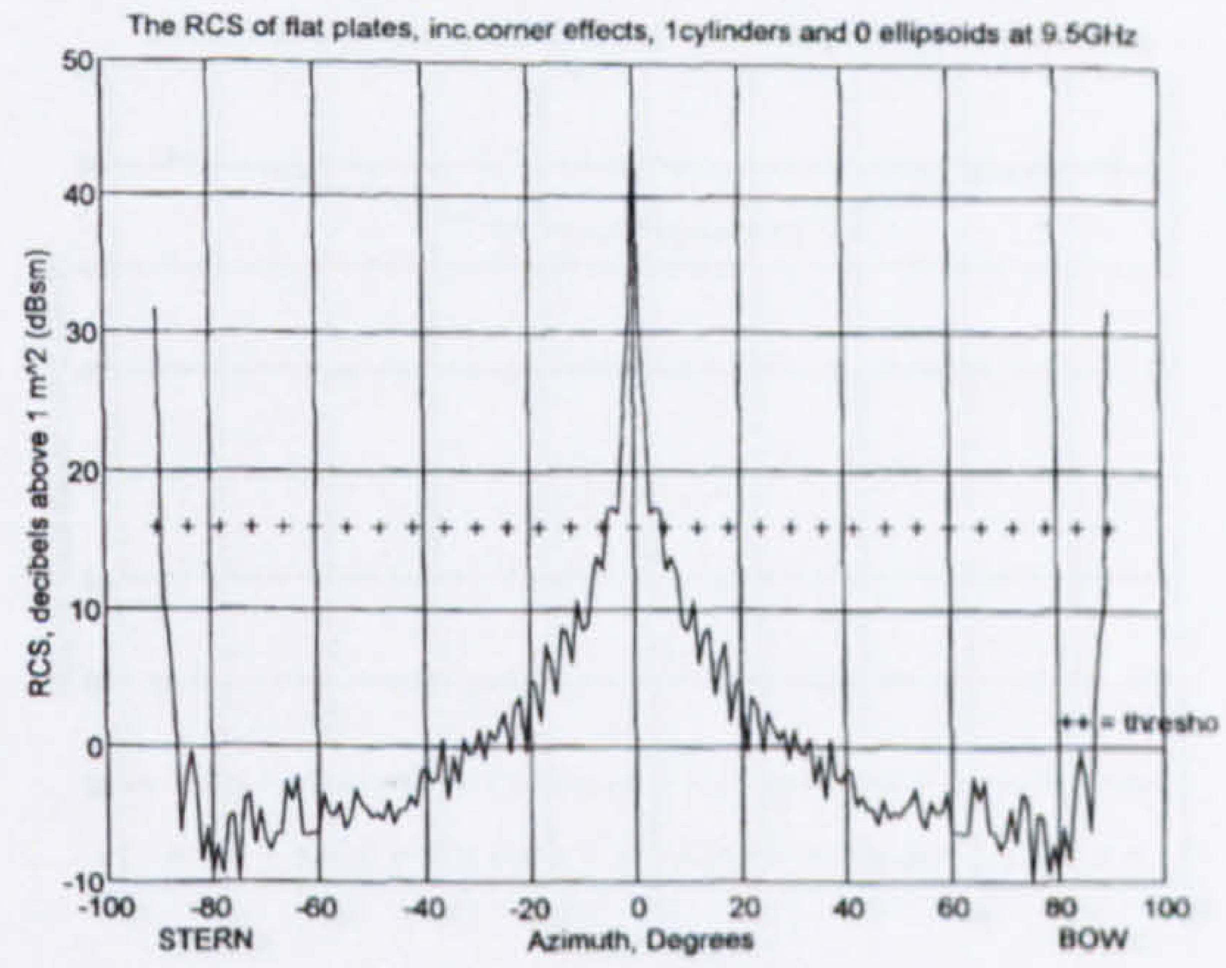


b) Secondary Reflections

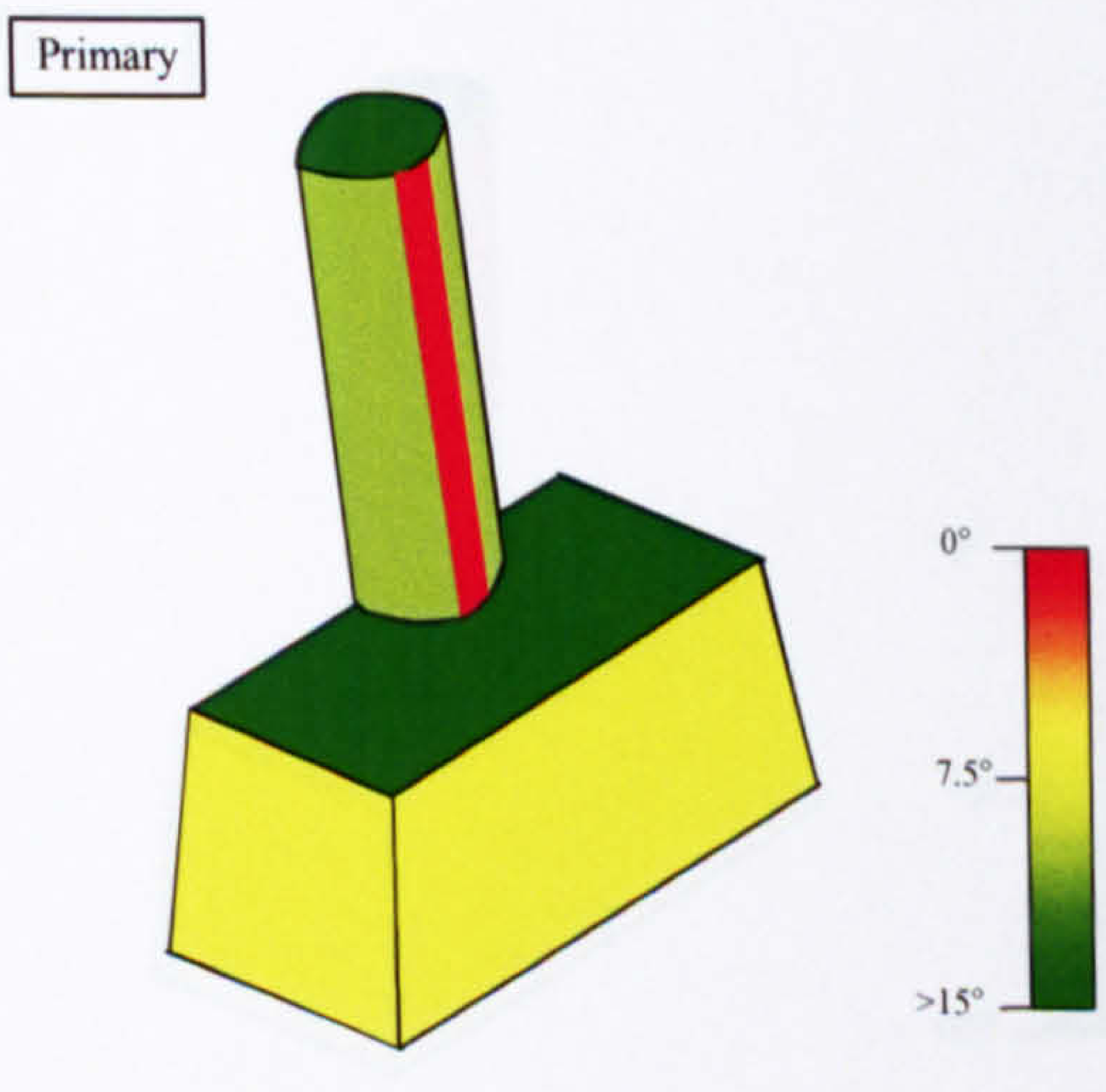
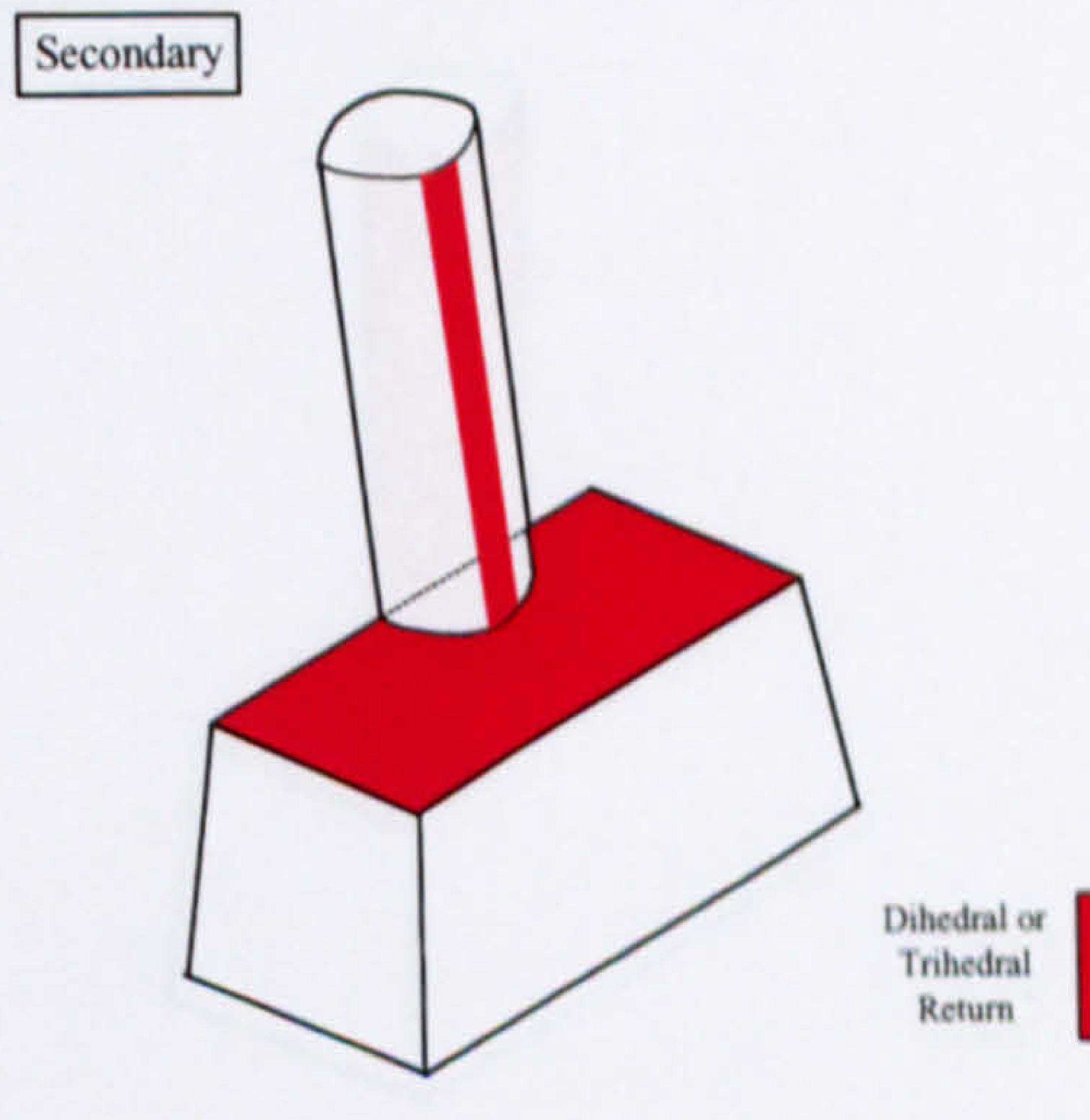


Note : this is a simplified version of the geometric analysis output for illustration purposes. In reality the cylinder shading would be graduated from red, in a beam on situation, through to a near yellow viewed for ahead and astern where the 5° angle is seen.

Model 14 : Base with 7° incline with circular mast at 10° incline

Model Definition	Results from SIRCS Analysis
	

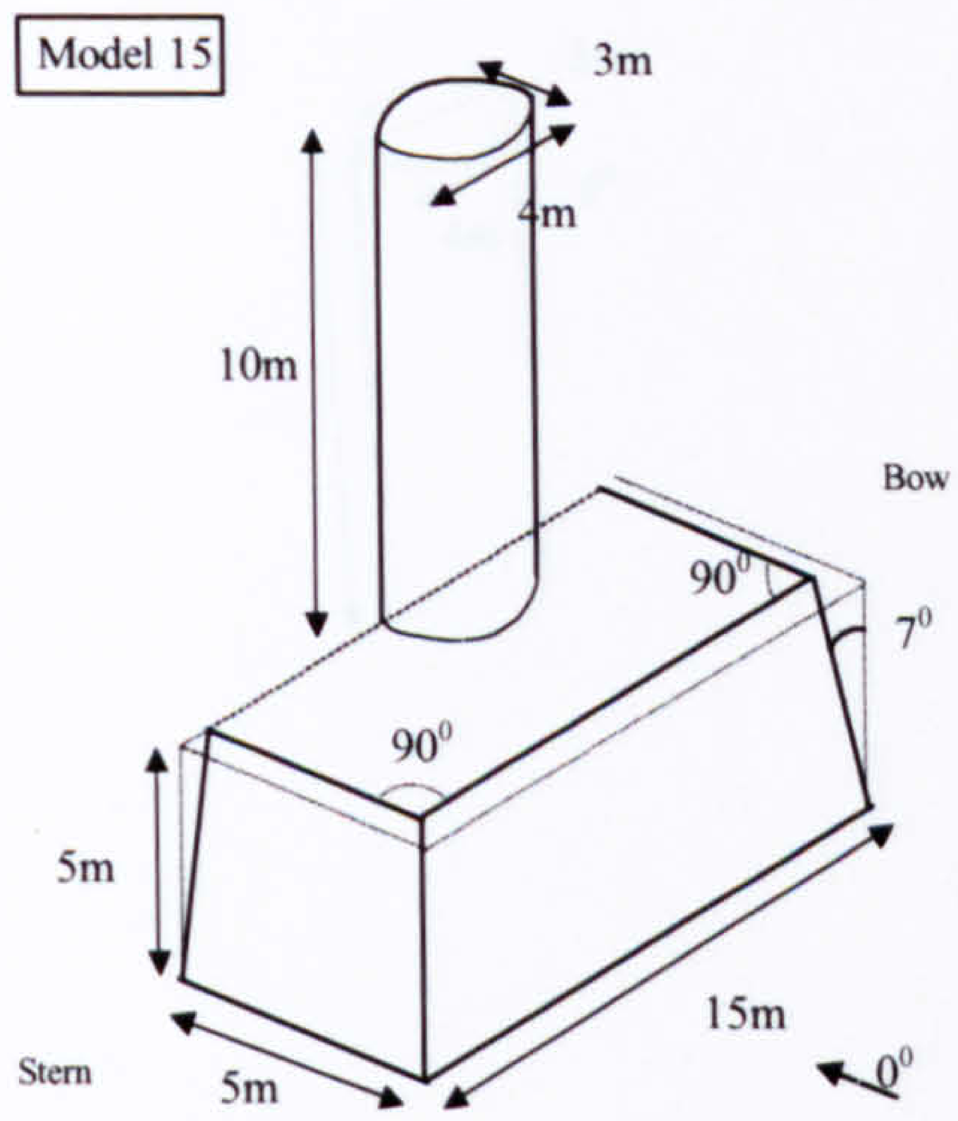
Results from the Geometric Analysis

a) Primary Reflections	b) Secondary Reflections
	

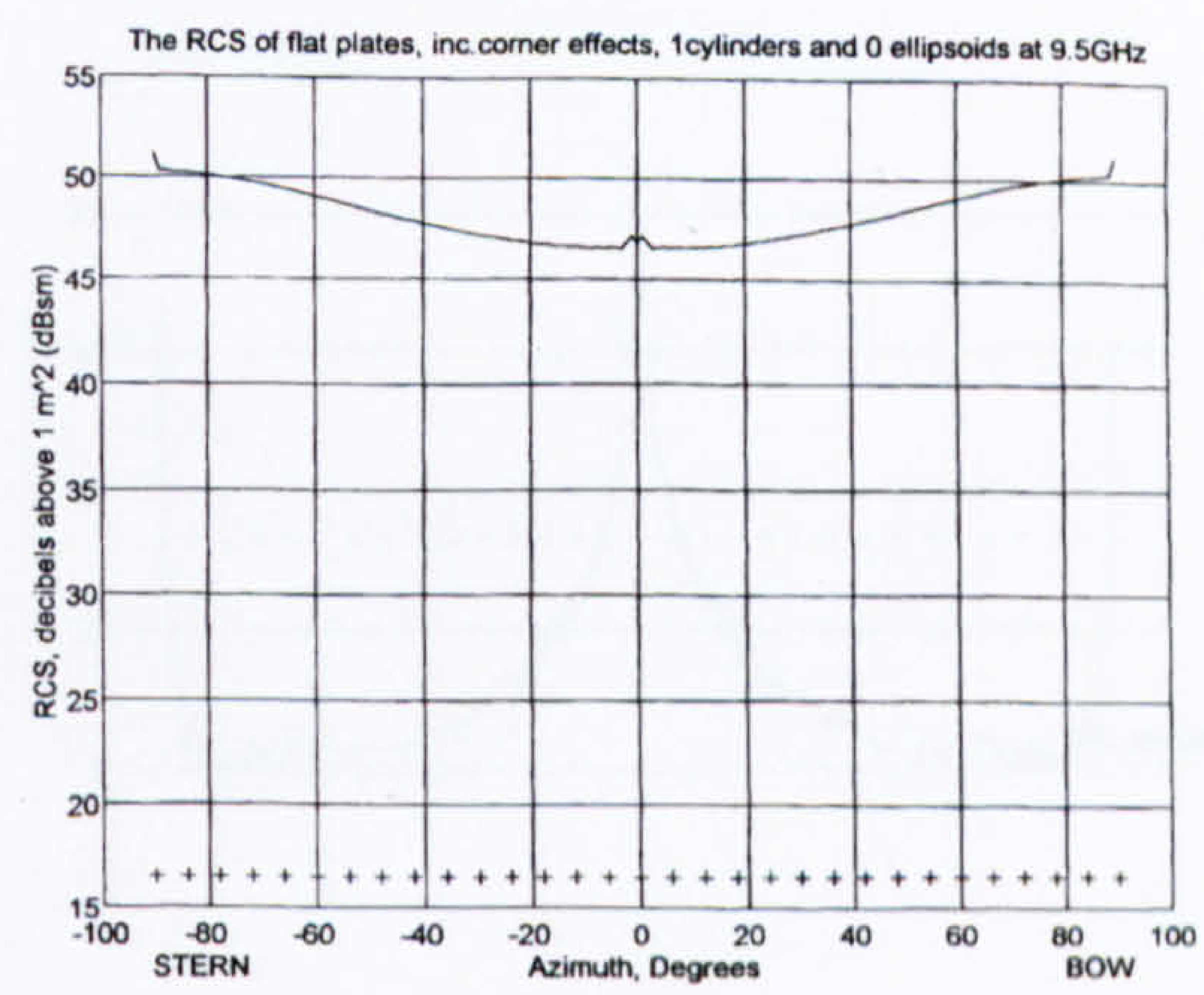
Note : this is a simplified version of the geometric analysis output for illustration purposes. In reality the cylinder shading would be graduated from red, in a beam on situation, through to a yellow/green viewed for ahead and astern where the 10° angle is seen.

Model 15 : Base with 7° incline with oval funnel at 0° incline

Model Definition

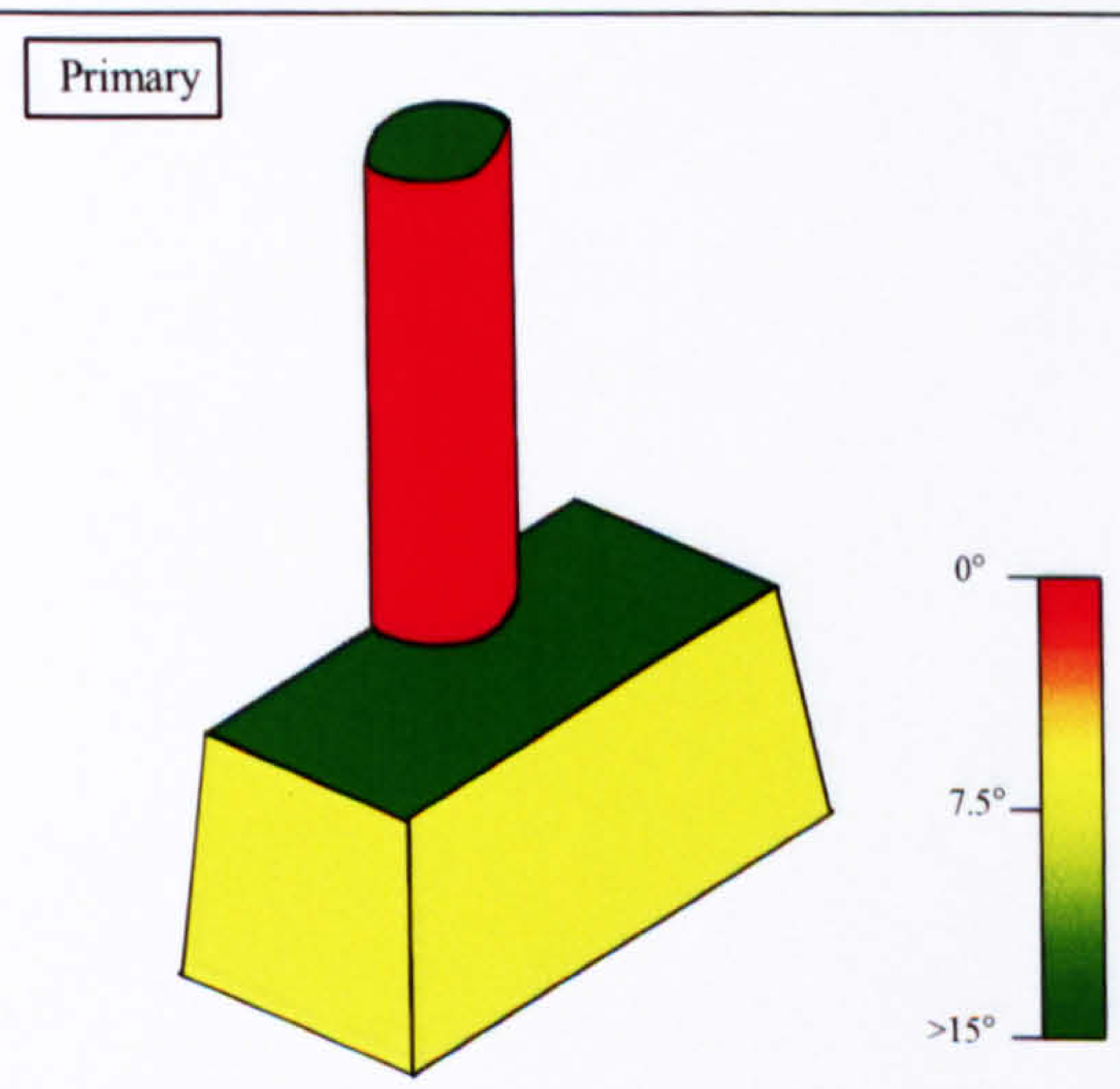


Results from SIRCS Analysis

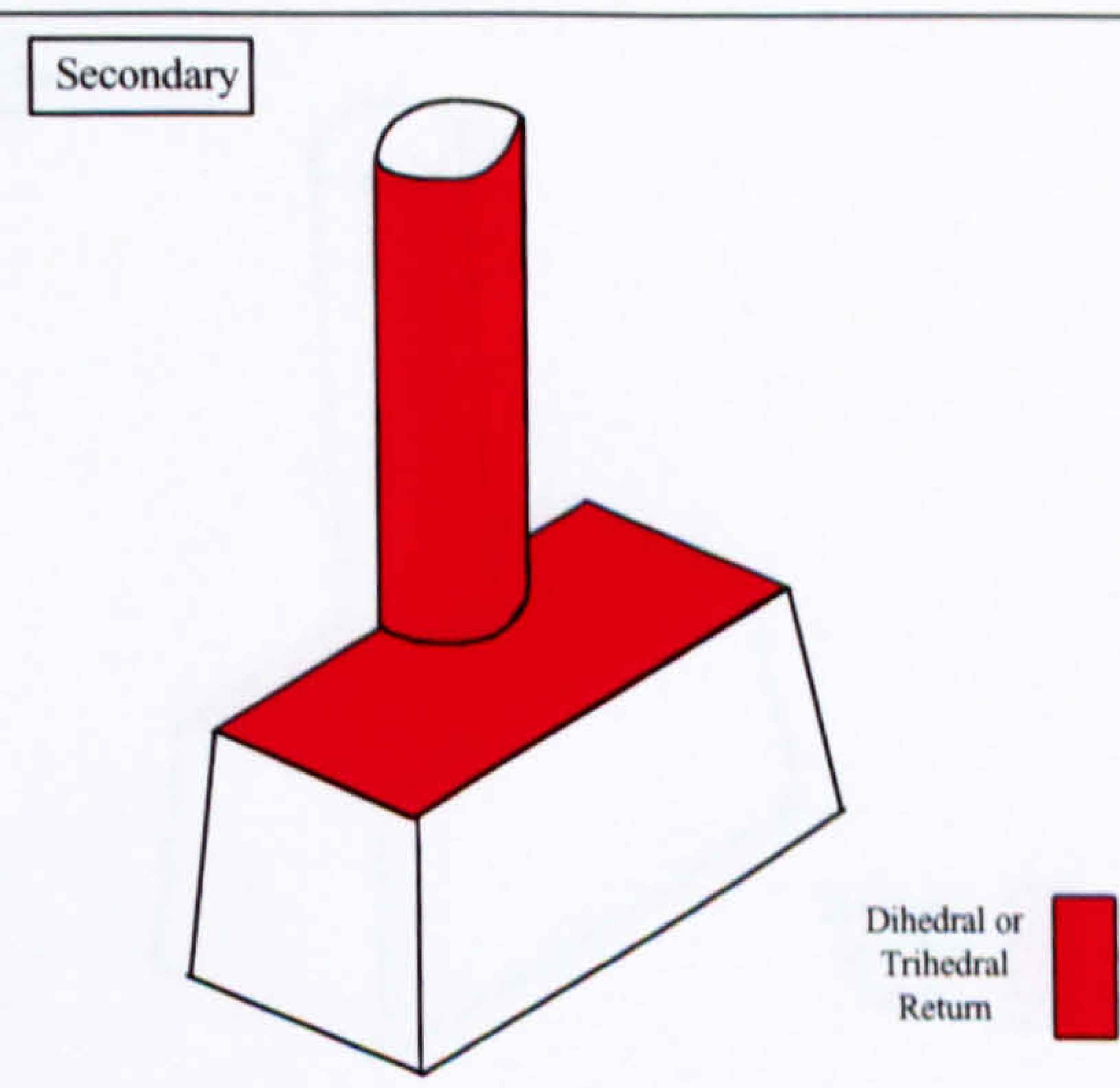


Results from the Geometric Analysis

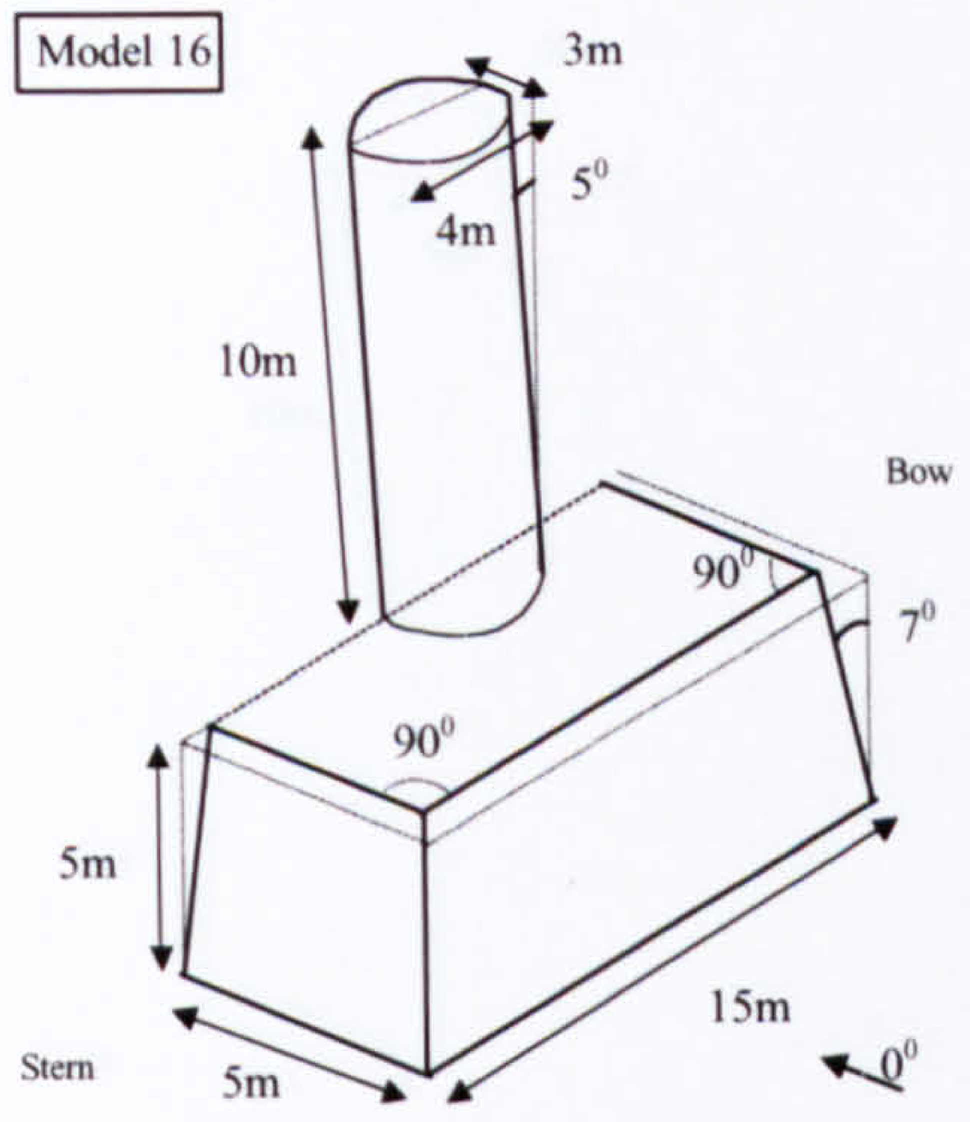
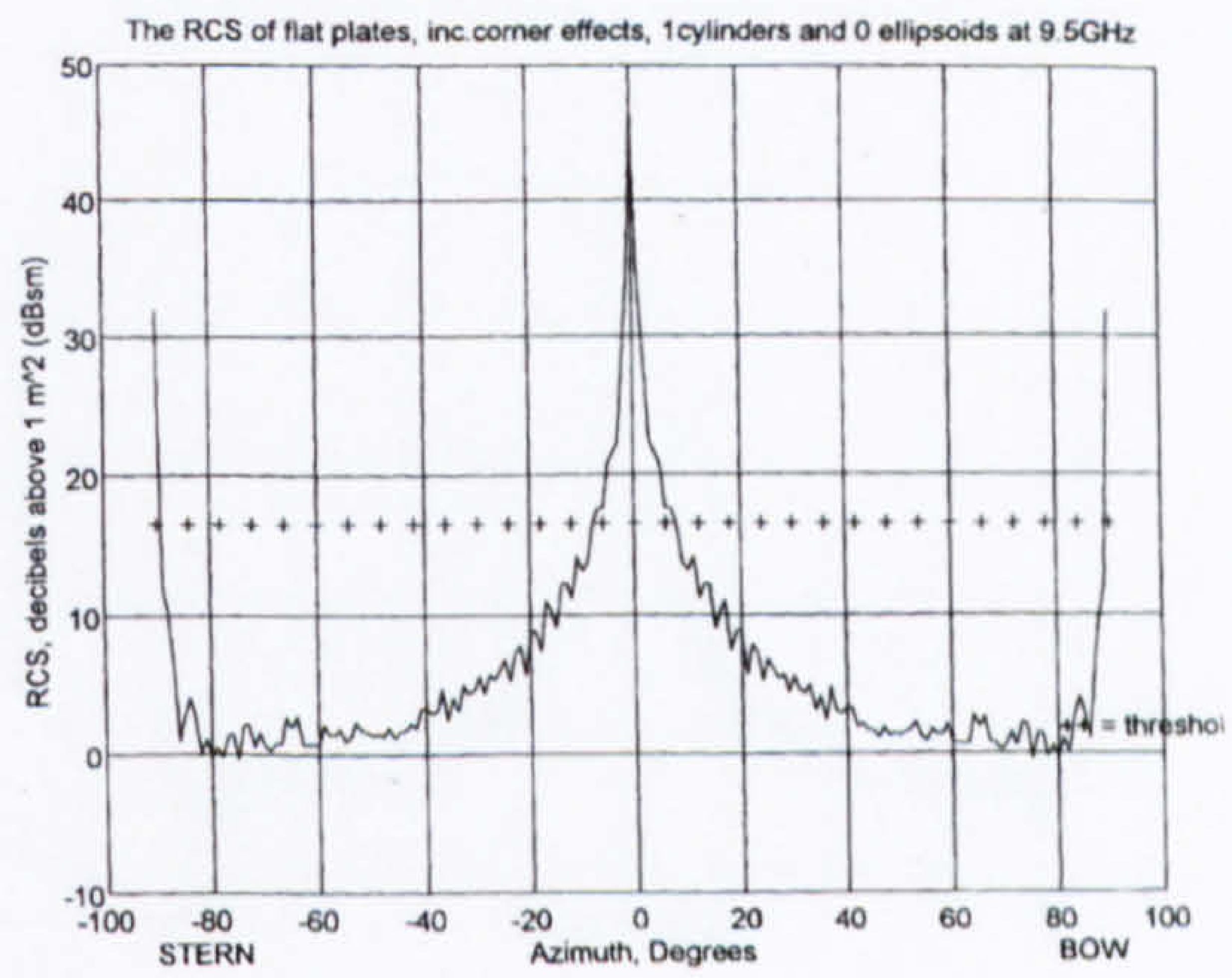
a) Primary Reflections



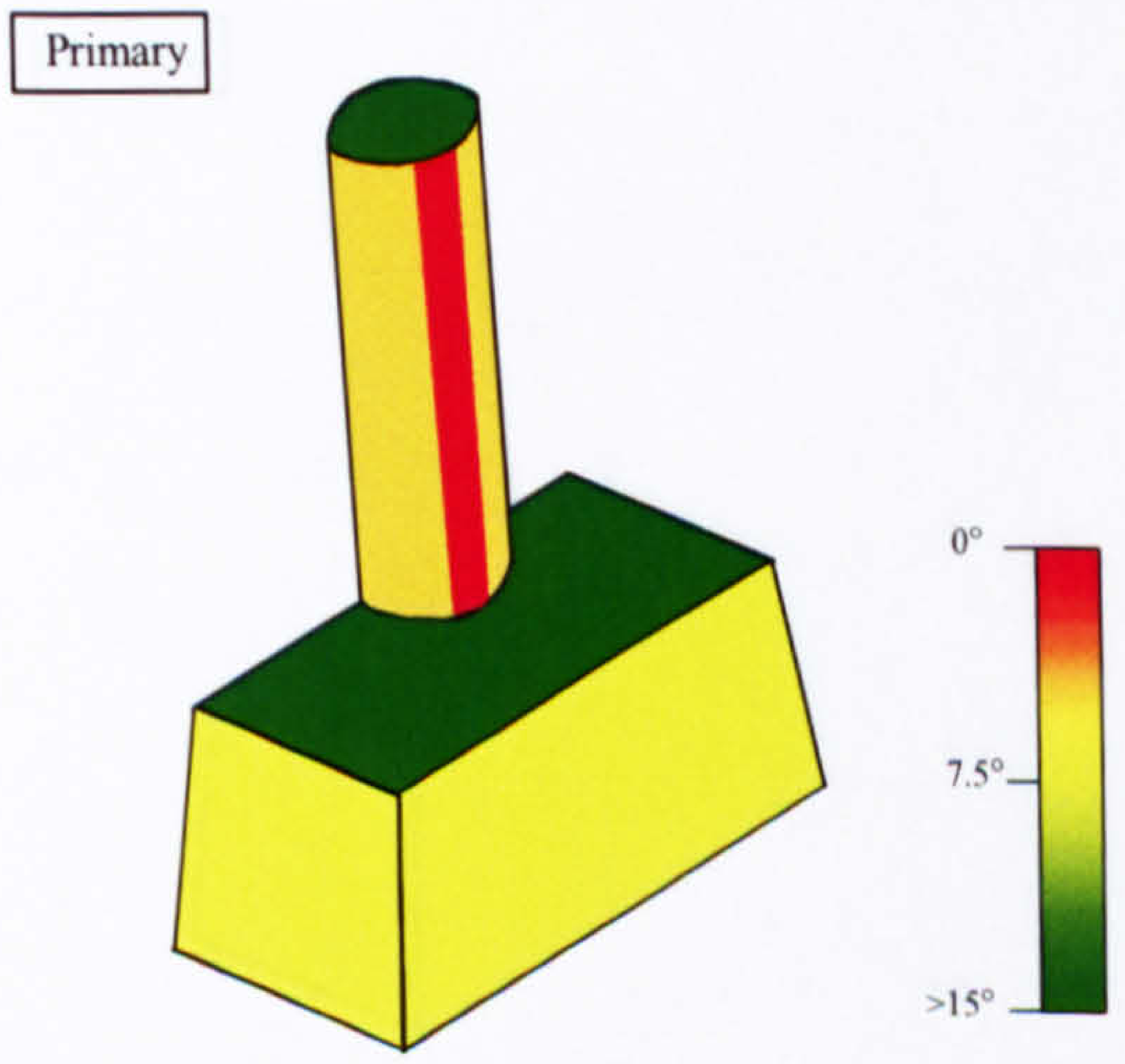
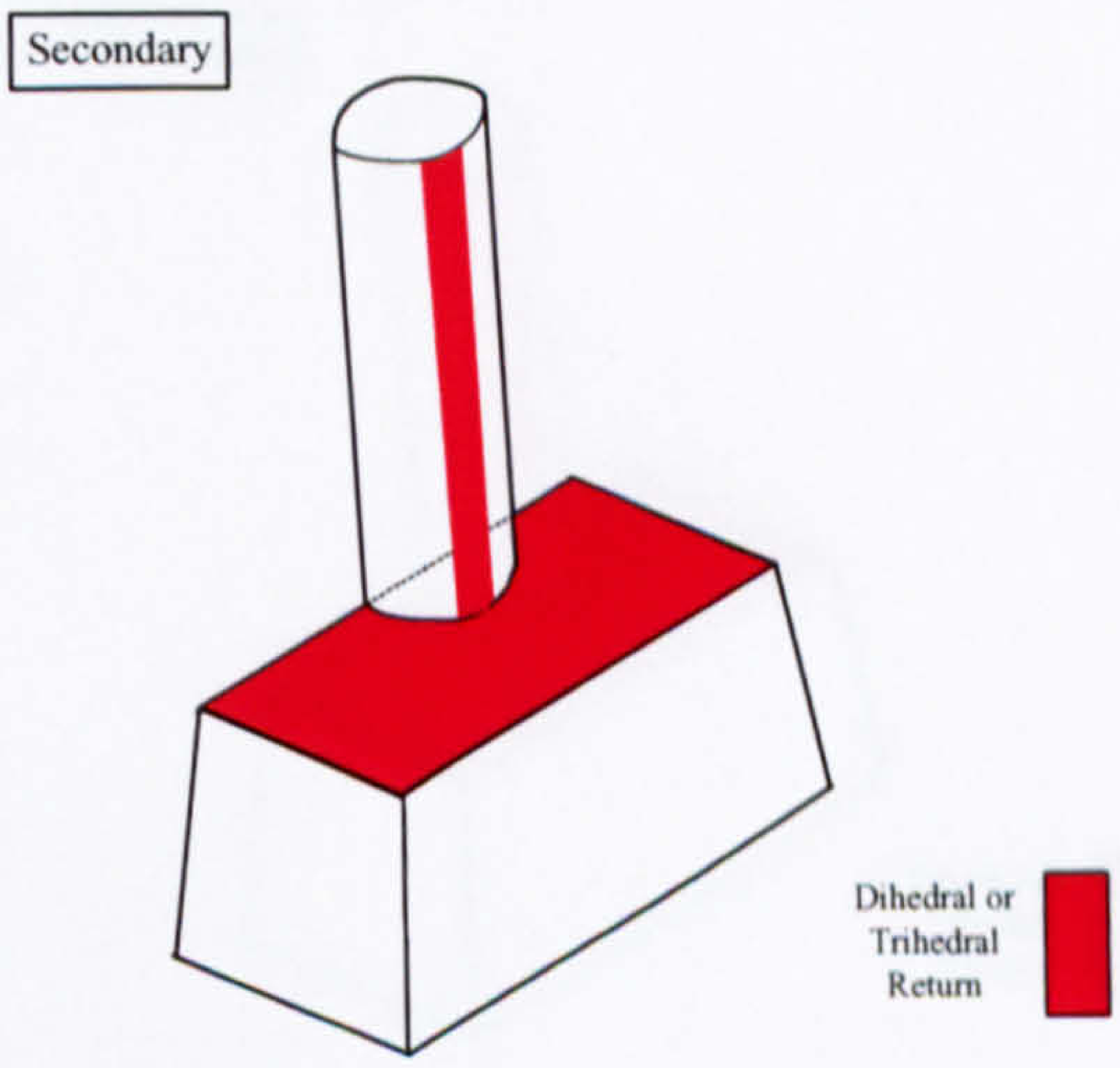
b) Secondary Reflections



Model 16 : Base with 7° incline with oval funnel at 5° incline

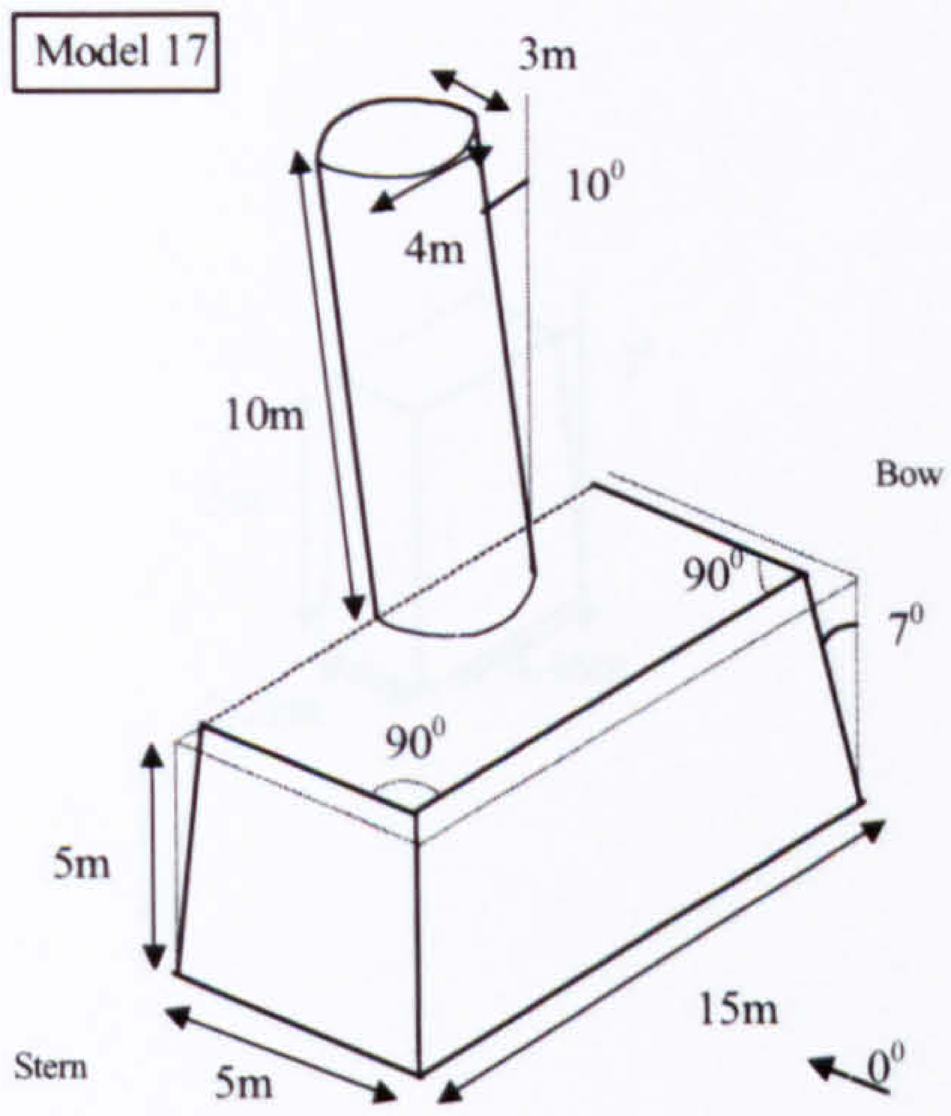
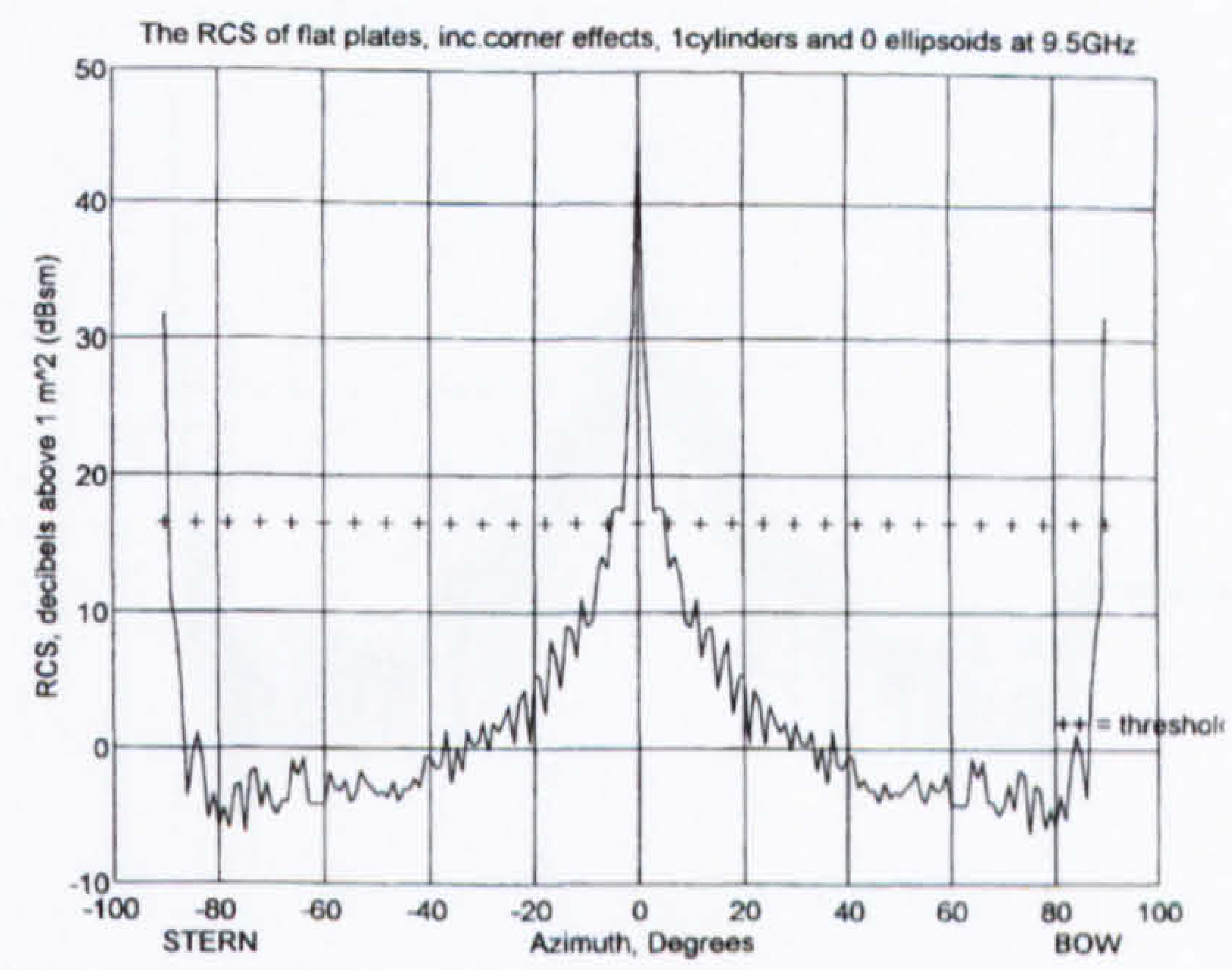
Model Definition	Results from SIRCS Analysis
	

Results from the Geometric Analysis

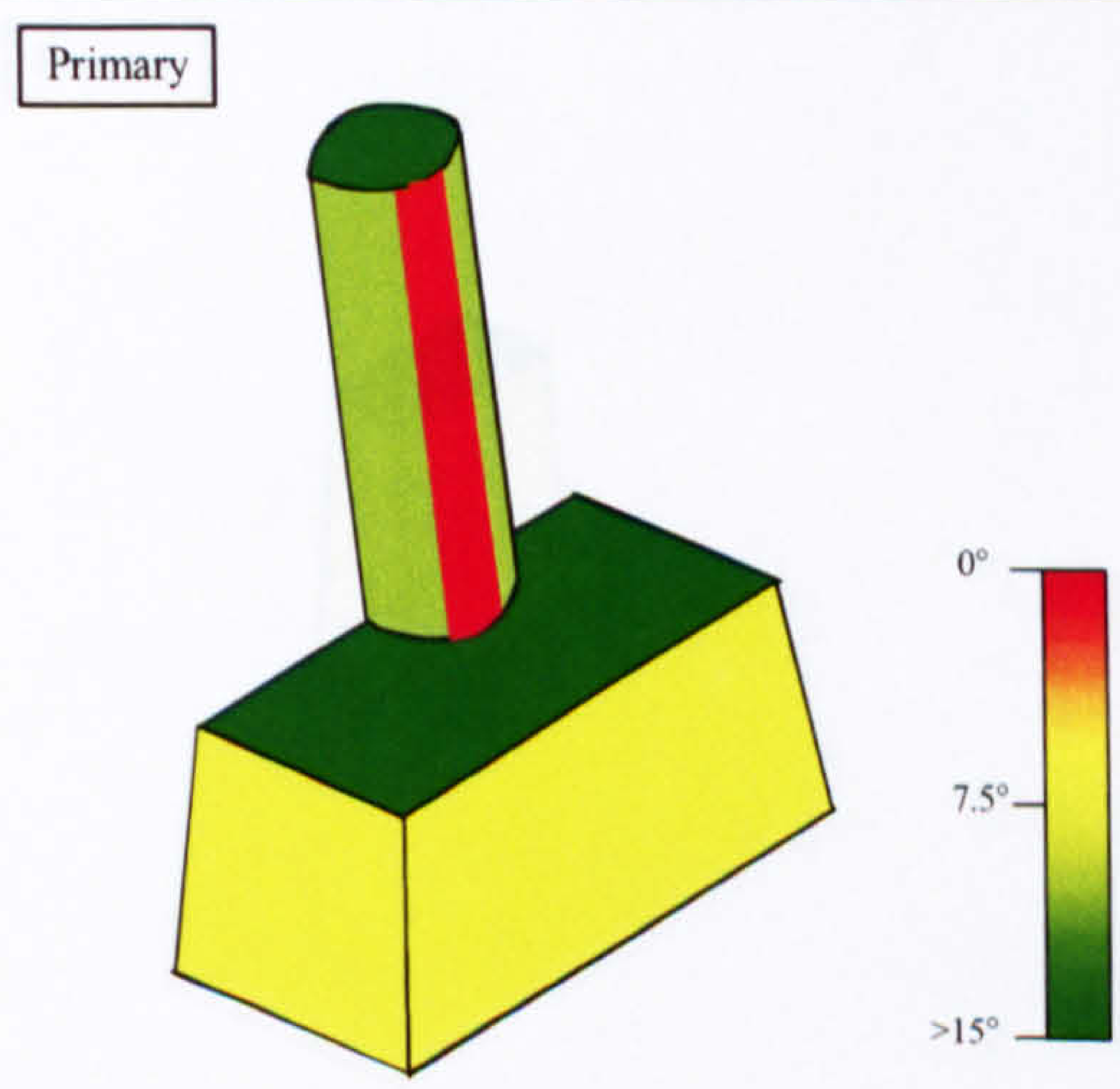
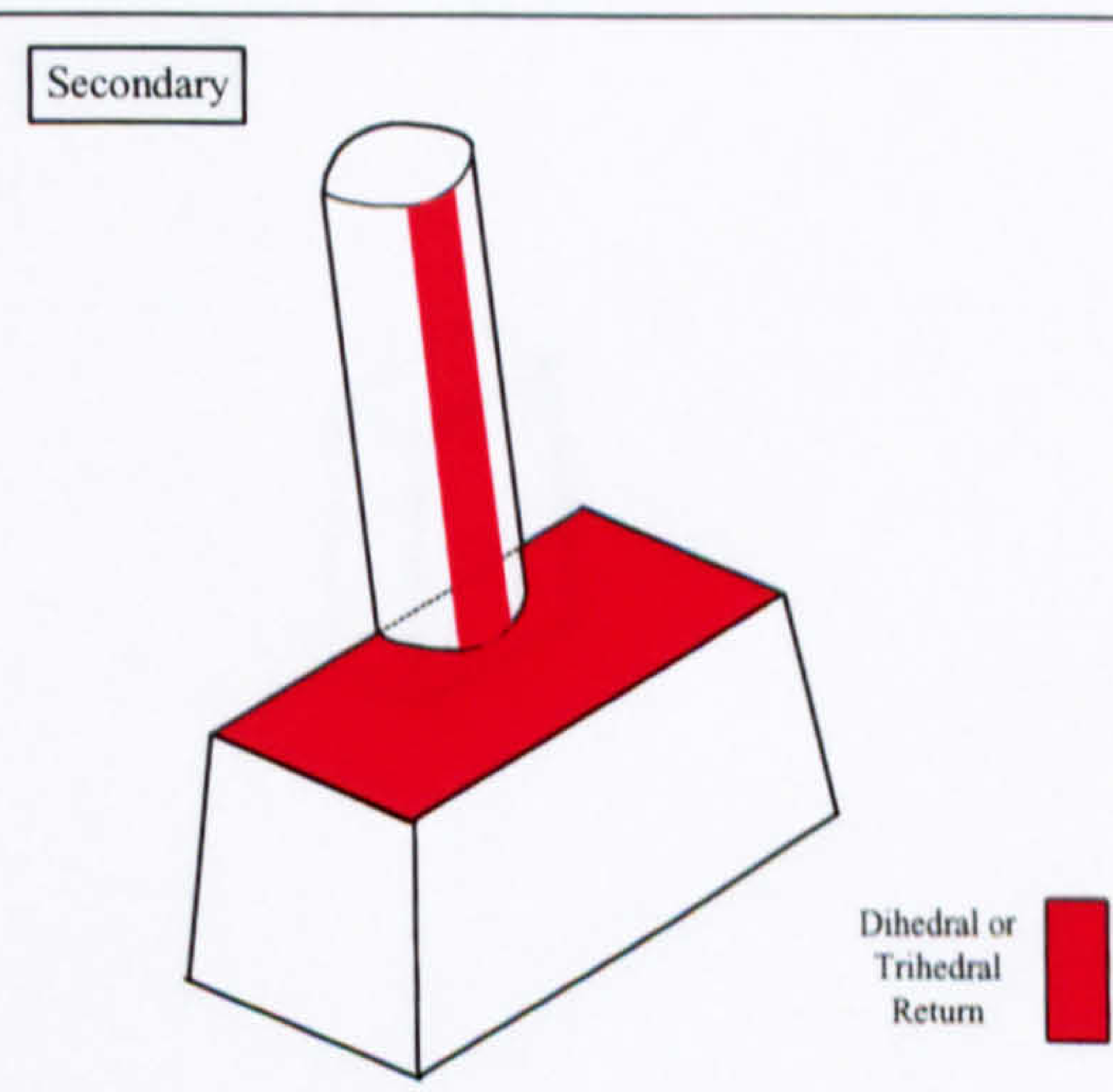
a) Primary Reflections	b) Secondary Reflections
	

Note : this is a simplified version of the geometric analysis output for illustration purposes. In reality the cylinder shading would be graduated from red, in a beam on situation, through to a near yellow viewed for ahead and astern where the 5° angle is seen.

Model 17 : Base with 7° incline with oval funnel at 10° incline

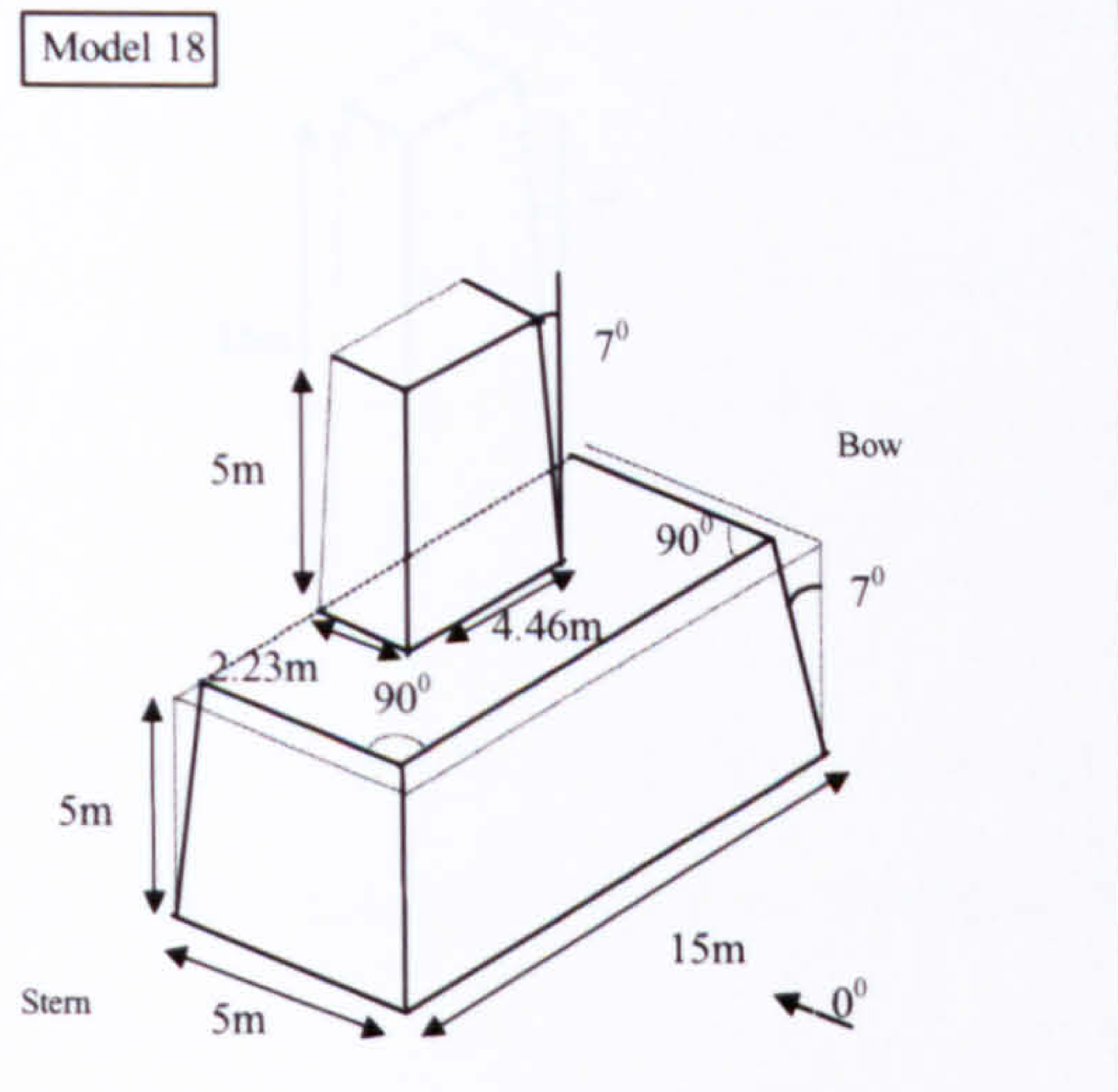
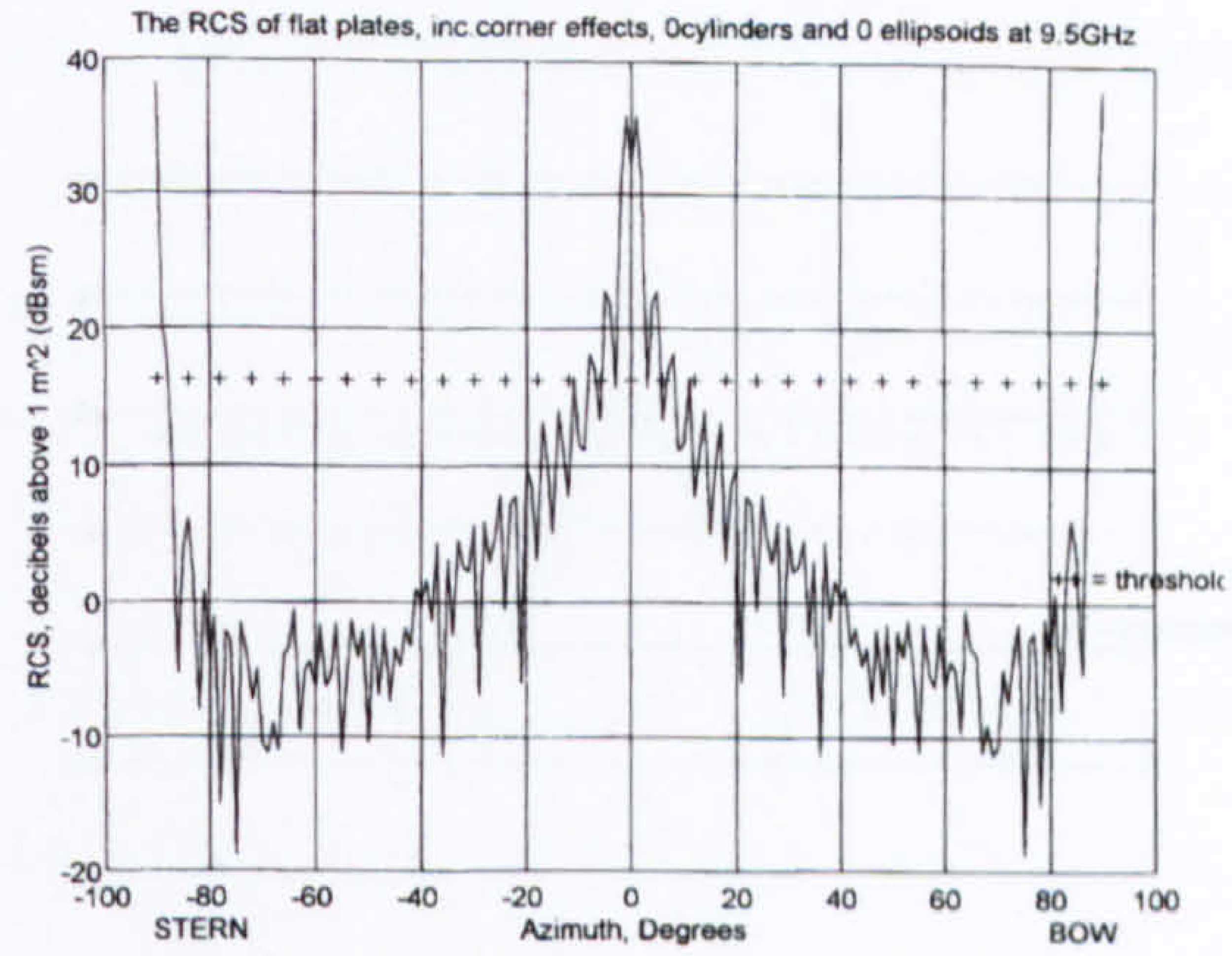
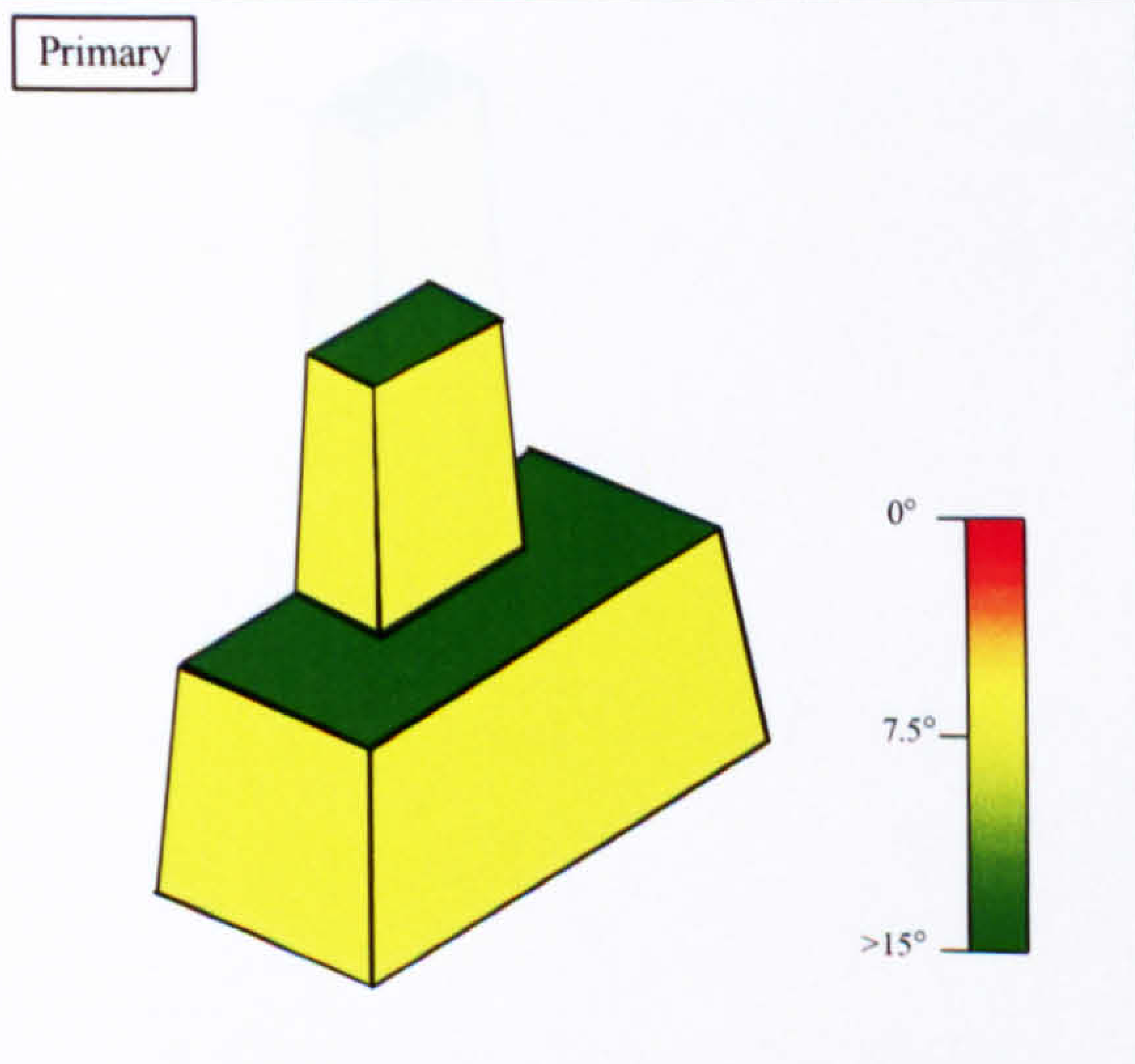
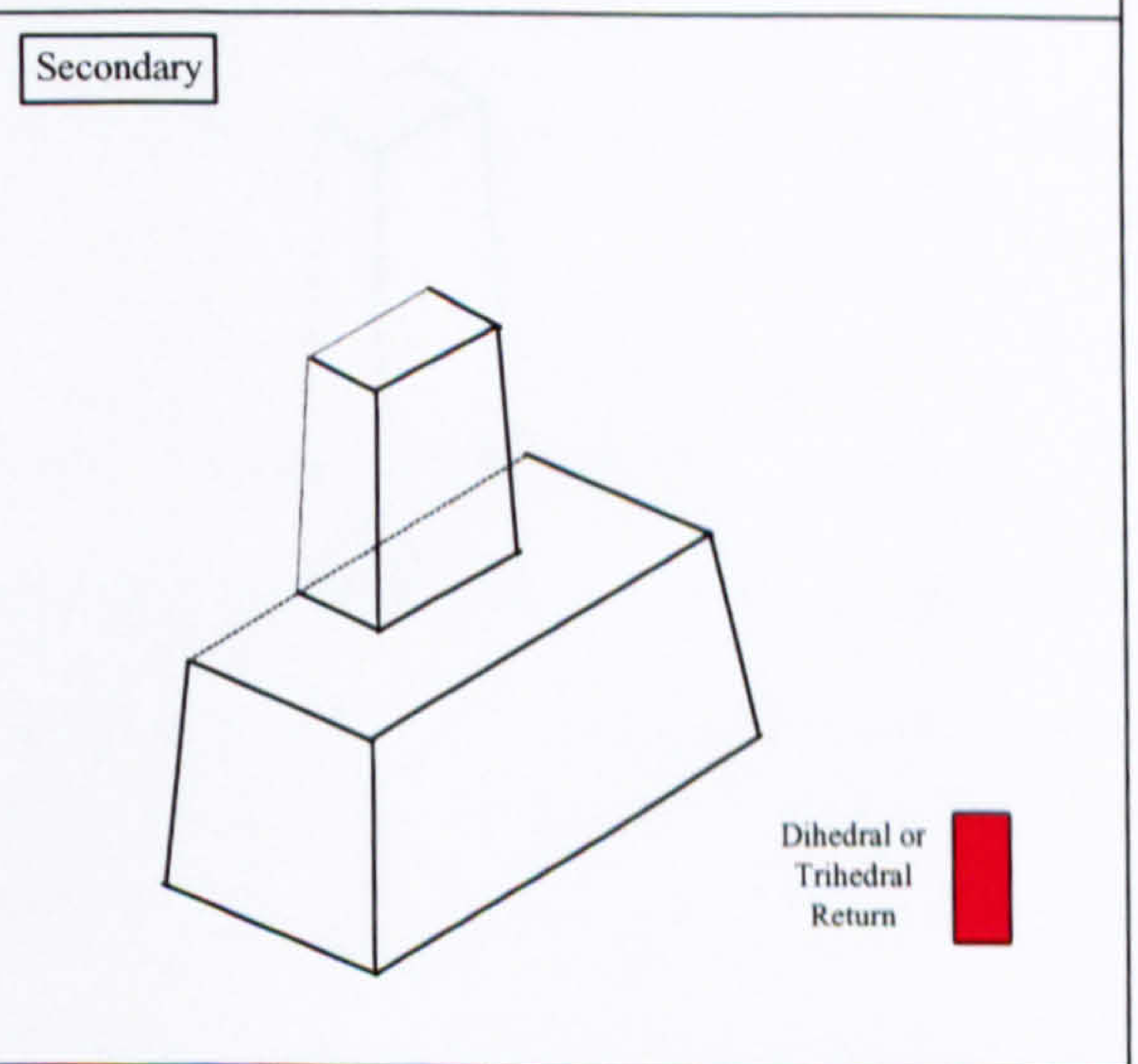
Model Definition	Results from SIRCS Analysis
	

Results from the Geometric Analysis

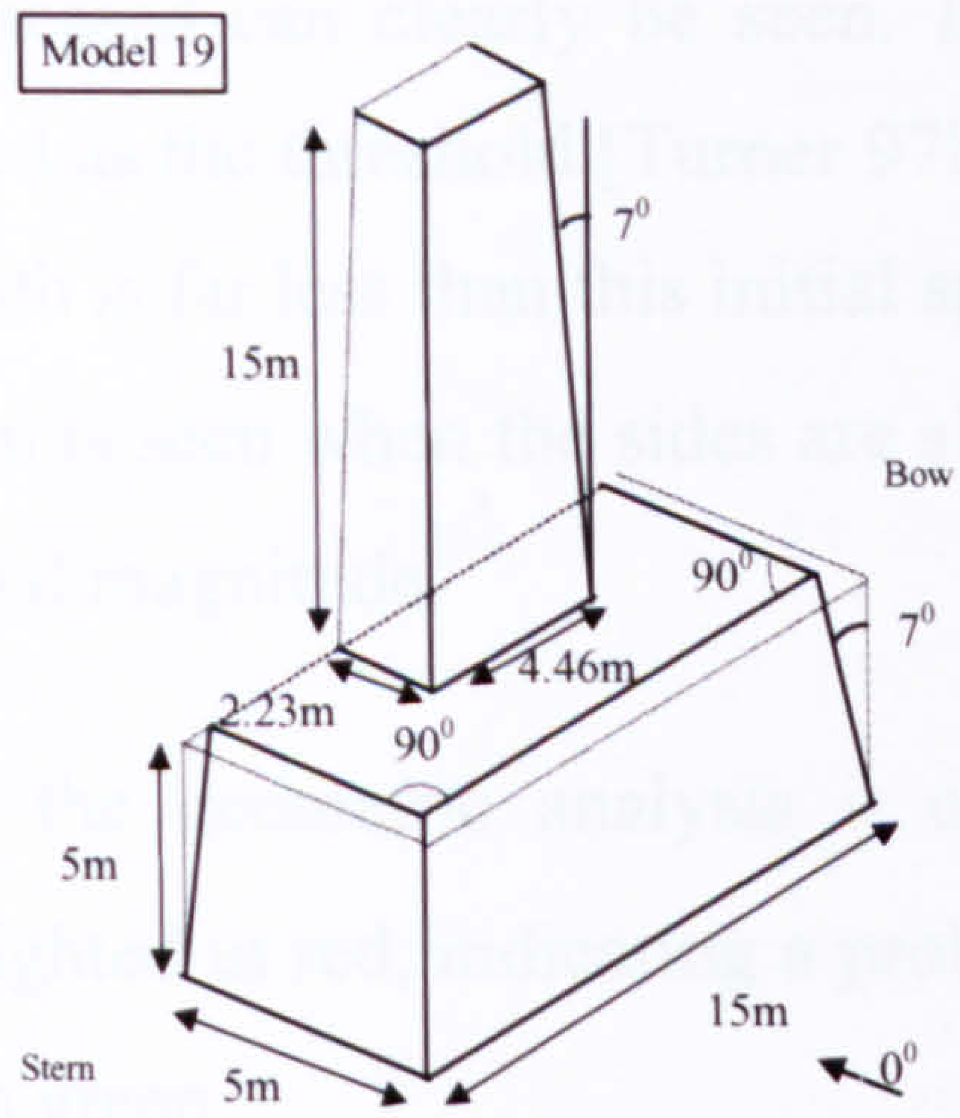
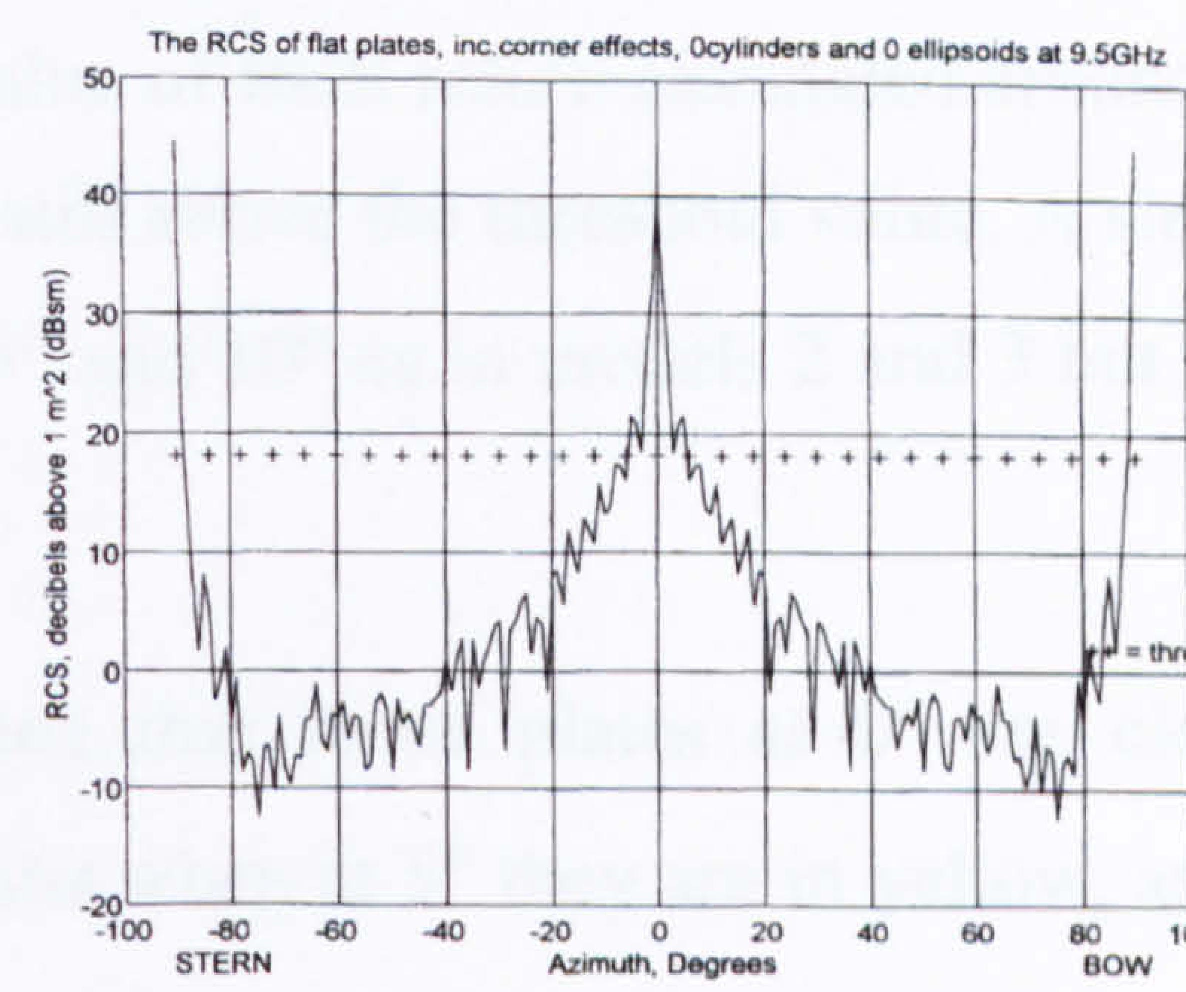
a) Primary Reflections	b) Secondary Reflections
	

Note : this is a simplified version of the geometric analysis output for illustration purposes. In reality the cylinder shading would be graduated from red, in a beam on situation, through to a yellow/green viewed for ahead and astern where the 10° angle is seen.

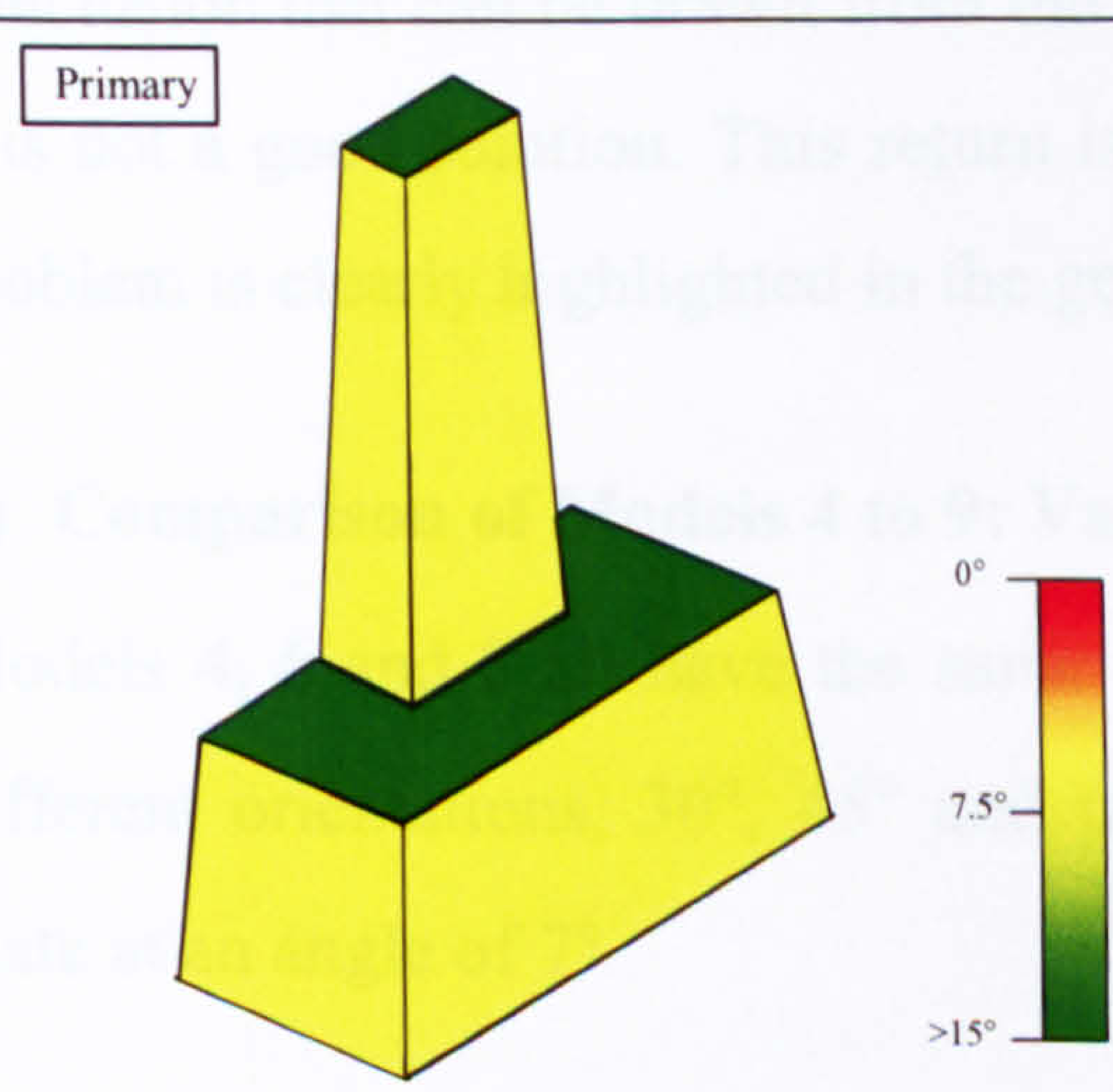
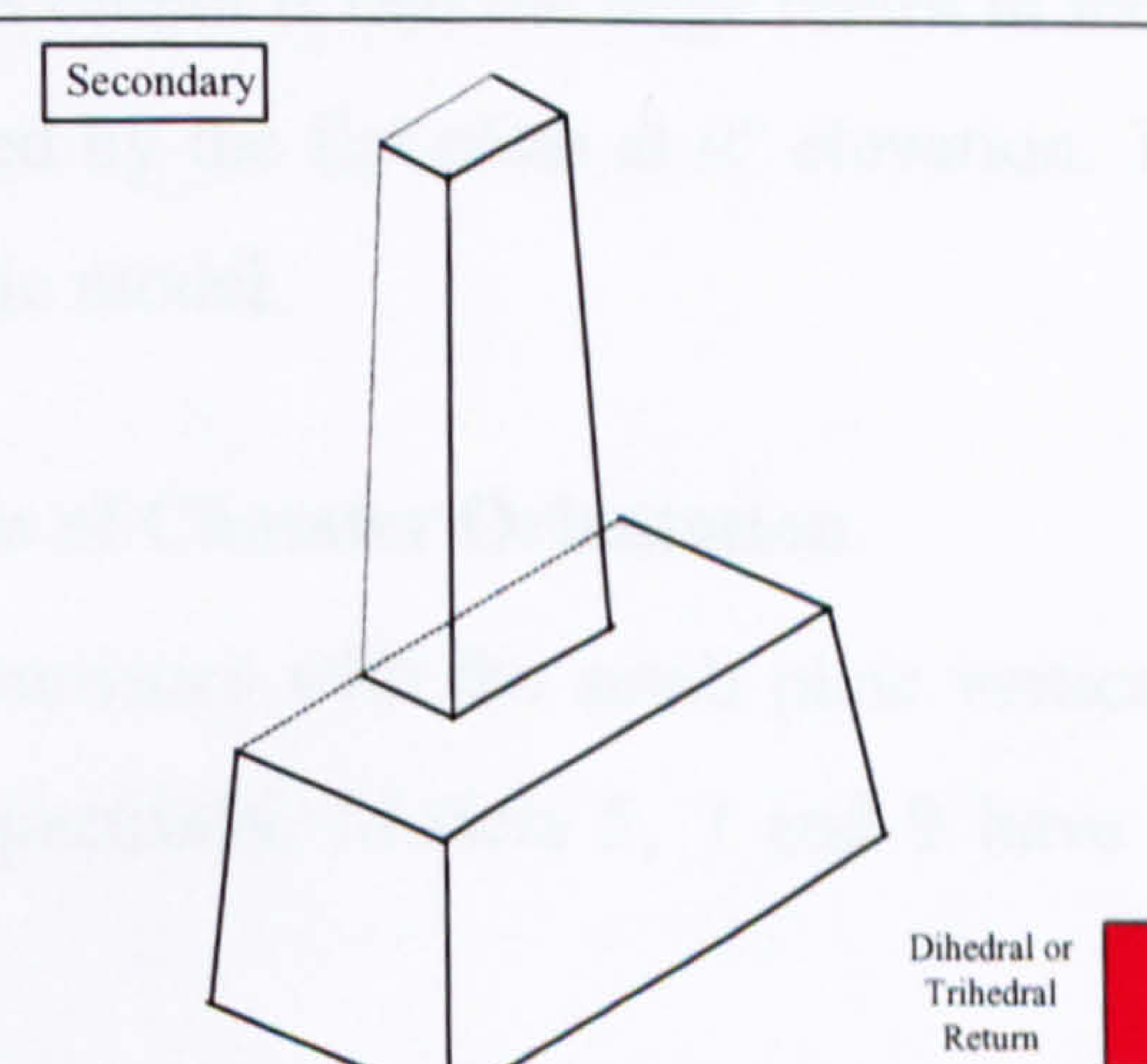
Model 18 : Base with 7° incline with short square mast at 7° incline

Model Definition	Results from SIRCS Analysis
	
Results from the Geometric Analysis	
a) Primary Reflections	b) Secondary Reflections
	

Model 19 : Base with 7° incline with tall square mast at 7° incline

Model Definition	Results from SIRCS Analysis
	

Results from the Geometric Analysis

a) Primary Reflections	b) Secondary Reflections
	

5.2. Discussion

5.2.1. SIRCS and Primary Reflectors

a) Comparison of Models 1 to 3: Variation in Tumblehome[155] on a Box

In the SIRCS output a large spike at 0°, reducing in magnitude as the angle of slope is increased can clearly be seen. In model 1 this has a value far higher than that defined as the threshold [Turner 97b]. The value of RCS return calculated around the azimuth is far less than this initial spike, but still above the threshold value. A similar pattern is seen when the sides are sloped at 5° and 10° as in models 2 and 3 but with reduced magnitude.

From the geometric analysis it can be seen that those plates at 0° are clearly highlighted in red, indicating a problem, whilst when at 5° they are in yellow, and at 10° in green.

Although the geometric model does not show the pattern of the RCS signal around the azimuth it is essentially capturing the same information. Due to the crude way in which the RCS formulas have been implemented it is not possible to calculate absolute RCS values, and so the SIRCS output can only be used for indication. The conclusion that can be drawn from the SIRCS output is that the large return in model 1 is not a good solution. This return is caused by the flat plate at 0° elevation. This problem is clearly highlighted in the geometric model.

b) Comparison of Models 4 to 9: Variation of Chamfer Orientation

Models 4, 6 and 8 all have the same characteristics with the small plate vertical at different orientations, 30°, 45° and 60° respectively. Models 5, 7 and 9 have this plate at an angle of 7°.

The specular return seen in the SIRCS output from this smaller plate is much larger then that of the broadside plate in models 4, 6 and 8 but is reduced in magnitude for

[155] A term defining the narrowing of a ship's breadth. It is the measure of the inward fall when the breadth is less than the maximum breadth [Chambers 91].

models 5, 7 and 9. The angle of the spike is seen to match the angle of the chamfer plate as expected. In models 5, 7, and 9 where the plate is sloped the spike reduces to a level below the other plates. The geometric model highlights this plate at 0° as being a possible problem. Although the geometric analysis is far simpler in nature compared to SIRCS, the same problem is highlighted to the user.

c) Comparison of Models 10 and 11: Plated Mast

The only difference between models 10 and 11 is the angle of the plating on the mast structure. The returns generated by the SIRCS program for model 10, are far larger than model 11. This is due to the plates at a 0° angle causing a large reflective surface. With these plates sloped as in model 11, this peak is reduced. The same information is captured by the geometric approach, highlighting in red the problem areas, in this case the mast with no slope.

d) Comparison of Models 12 to 17: Variation of Circular and Elliptical Masts

The SIRCS results for Model 12 are dominated by the return from the vertical cylinder. As the cylinder cross section is circular around the azimuth the reflected energy is constant as there is always a direct reflection present. The only way to reduce the flash width is to tilt the cylinder away from the vertical. This effect can be seen in the results from models 13 and 14 but the maximum return has not changed as there is still a point where a direct return is unavoidable. The results of model 15 show the vertical elliptical cylinder's effect on RCS with variation of the cross section of the cylinder. Again the returns are reduced when this cylinder is tilted, models 16 and 17.

In the geometry check, as there is no flat plate, the output will be a graduated shading ranging from red where the return is direct to more favourable results as the angle of the surface changes due to the tilt on the cylinder. This output has been simplified for this investigation as the results were not generated by the computer. This output can be easily interpreted by the designer with the possible problem areas highlighted. In this case the use of a cylindrical mast means that a direct reflection path is unavoidable, this will be highlighted to the designer as an area of red on the mast.

e) Comparison of Models 11, 18 and 19: Variation in Mast Height

For all three models the overall geometry is similar. Although the SIRCS program shows differences in the levels of return, what is shown is that reducing area reduces the return. The SIRCS program cannot predict absolute values due to the crude implementation of formulas and so the only valid conclusion that can be drawn is that smaller surface area is better. This information is not conveyed in the geometric model as no account is taken of the surface areas producing the returns. In all cases, due to the same slope angle being used, the shading is the same. Although a possible failing of the geometric approach, this surface area problem highlights the need for an educated user.

5.2.2. Secondary Reflectors and Design Angle Returns

a) Discussion on Secondary Returns

An example of the output obtainable for the Secondary Returns analysis is shown for models 10-19. Surfaces highlighted in red show where there is a 90° angle between the surfaces. This is clearly a problem, where a dihedral or trihedral reflector is created. Although appearing very simplistic on these simple models the principle can be seen. With a more complex geometry this simple highlighting will aid the user in avoiding these possible problem areas. The aim of this analysis is to expose any possible geometric problems between different areas of superstructure or equipment.

b) Discussion on Design Angle returns

Models 1-9 have been used to illustrate the Design Angle Return output. Those surfaces deviating markedly from the primary design angle are highlighted. Again this is seen to be very simplistic with these models. However this option allows the designer to easily determine the dominant angle and those surfaces that may require adjustment to fit in with the overall design. The simple colour coded output does not confuse but shows possible problems allowing informed decisions to be made.

APPENDIX 6

6. SCENARIO MODELLING DATABASE REQUIREMENTS

6.1. Database Requirements

The database has been split into five sections, each detailing different types of equipment. This is due to the fact that different equipment items require different data to be recorded. The five sections are shown below and detailed in the following subsections (6.1.1 to 6.1.5) where brief explanation of the data requirements and an example of each type of entry are presented. Full details along with further example entries can be seen in the reference [Skarda 98].

- Sensor Records
- Missile System Records
- Gun System Records
- Electronic Warfare System Records
- Threat Records

6.1.1. Sensor Records

Sensor Name	-	An identifying name for the system.
Optical?	-	A TRUE/FALSE data field that describes the type of sensor. This is required when calculating the sensor horizon, an electronic sensor can have a greater horizon than an optical sensor [Skarda 98].
Radar?	-	A TRUE/FALSE data field describing the type of sensor, this can also be used to indicate possible system interaction between directors and weapon systems.
Surveillance?	-	A TRUE/FALSE data field indicating whether the system is used as a surveillance radar.
Fire Control?	-	A TRUE/FALSE data field indicating whether the system is used as a fire control radar.
Detection Range	-	This field is used to place a limit on the maximum detection range for the system. Where a high altitude threat is detected the range of detection is not necessarily limited by the horizon but by the power of the system.
Fire Control Channels	-	This field relates to the number of targets that can be illuminated by the system. This becomes important when considering multiple incoming threats and determines how many missiles a single system can be used to track.
Notes	-	Allows information to be recorded to aid a user in deciding which other equipment items are usually associated with this equipment.

Image removed due to third party copyright

Figure A6.1 : Example Sensor Database Entry [Skarda 98]

6.1.2. Missile System Records

System Name	- An identifying name for the system.
Missile Velocity	- The speed at which the missile flies. This is assumed to be the outgoing velocity of the missile. For more complex missiles, with varying outgoing speed, the speed profile has to be recorded here.
Maximum Range	- Defines the maximum range at which the system can engage a target.
Minimum Range	- Defines the minimum range at which the system can engage a target.
Time Between Launches	- This is the time required before a second missile can be launched from the same launcher. This allows for frangible covers to be blown clear and the first missile to be in flight before firing a second missile.
Probability of Kill per Missile	- The probability of a missile being successful against the target. Used in the overall probability calculation.
Number of Rounds in Launcher	- This is the number of missiles ready for firing. This will limit the total number of missile launches possible before reloading is required.
Threat Evaluation Period	- This is the time taken by the system to identify the threat as a valid threat and assign it as such. This may be an automatic process or may involve manual intervention from the crew. This data item is additional to those used in the simplified exercise where threat evaluation and reaction time were considered as one item.

Reaction Time	- This is the time taken by the system to react to the valid threat, this may involve moving a trainable mount and priming the weapons ready to fire. This must be carried out before the weapon can fire.
Kill Assessment Period	- This is the time taken by the system, after the impact time, to assess whether the threat has been destroyed.
Reload Time	- For reloadable launchers this is the time taken to reload. This is most often an automated process.
Seeker Field of View	- When in flight a missile has a field of view due to the onboard sensor, this is used to increase the physical arcs of the system.
Launcher Type	- A flag to indicate if the system is vertical launch, where there will be full 360° coverage, or a trainable launcher where arcs of coverage information is required.
Sensor Requirements	- These records are TRUE/FALSE records that indicate the type of sensors required by the system. This information is used with the sensor database to ensure that compatible sensors are fitted. Indication is given as to whether the system has self contained sensors.
Guidance Information	- This details the type of guidance required by the missile. If the missile is guided from the ship the director must be able to see the threat for the duration of the engagement to guide the outgoing missile. Where the missile is actively guided internally, once launched continuous illumination of the target is not required.
Notes	- Allows information to be recorded to aid a user in deciding which other equipment items are usually associated with this equipment.

Image removed due to third party copyright

Figure A6.2 : Example Missile System Database Entry [Skarda 98]

6.1.3. Gun System Records

System Name	- An identifying name for the system.
Rate of Fire	- Details the rate of fire for the gun system.
Number of Ready Use Rounds	- This details the number of rounds available to the system before requiring a reload. Used in combination with the rate of fire this limits the total maximum time for which the weapon can fire.
Muzzle Velocity	- The speed at which the shell is fired. This is assumed to be the outgoing velocity of defensive salvo.
Maximum Range	- Defines the maximum range at which the system can engage a target.
Minimum Range	- Defines the minimum range at which the system can engage a target.
Probability of Kill per Round	- The probability of an individual shell being successful against the target. Used in the overall probability calculation.
Threat Evaluation Period	- This is the time taken by the system to identify the threat as a valid threat and assign it as such. This may be an automatic process or may involve manual intervention from the crew.
Reaction Time	- This is the time taken by the system to react to the valid threat, this may involve moving a trainable mount and priming the weapons ready to fire. This must be carried out before the weapon can fire.
Kill Assessment Period	- This is the time taken by the system, after the impact time, to assess whether the threat has been destroyed.

Burst Length - This is the maximum time the gun can fire for before it stops firing to cool down and carry out a kill assessment. This maximum may not be achieved in practice, dependant upon the speed of the incoming threat, but must not be exceeded.

Sensor Requirements - These records are TRUE/FALSE records that indicate the type of sensors required by the system. This information is then used with the sensor database to ensure that compatible sensors are fitted. Indication is also given as to whether the system has self-contained sensors.

Sensor Range - Where the system has self-contained sensors the detection range is given as this will not be captured in the sensors database.

Notes - Allows information to be recorded to aid a user in deciding which other equipment items are usually associated with this equipment.

Image removed due to third party copyright

Figure A6.3 : Example Gun System Database Entry [Skarda 98]

6.1.4. Electronic Warfare System Records

System Name	-	An identifying name for the system.
Type of System	-	This allows the system to be designated either a jammer or a decoy.
System Characteristics	-	This records whether the system is fixed or trainable. If the system is fixed the field of coverage is recorded.
Probability of Kill	-	This is the probability that the Electronic Warfare system will be successful in defeating the threat.
Notes	-	Allows information to be recorded to aid a user in deciding which other equipment items are usually associated with this equipment.

Image removed due to third party copyright

Figure A6.4 : Example EW System Database Entry [Skarda 98]

6.1.5. Threat Records

System Name	- An identifying name for the system.
Missile Speed	- The speed of the incoming threat.
Terminal Attack Altitude	- This records the altitude at which the threat makes an attack. This is required to determine the sensor horizon and the range at which the threat can be detected. Where there is a complex terminal phase the trajectory would be recorded here. This will allow for missiles with all forms of approach to be recorded. This would necessitate additional fields to allow this information to be recorded.
Country of Origin	- This field allows the user to see which equipment is likely to be met for any particular scenario.
Notes	- Allows information to be recorded to aid a user in deciding which other equipment items are usually associated with this equipment.

Image removed due to third party copyright

Figure A6.5 : Example Threat Database Entry [Skarda 98]

APPENDIX 7

7. RANGE – TIME DIAGRAM CALCULATION

7.1. Range - Time Diagram Calculation

Range -Time Graph for Example Engagement Scenario

Input Data

	Defensive System Seawolf 32 Cell VLS	Threat MM40 Exocet
Missile velocity	Mach 2.0	Mach 0.9
Maximum range	6000 m	-
Minimum range	500 m	-
Time between launches	1.20 s	-
Probability of kill per missile	0.36	-
Threat evaluation time	6.00 s	-
Reaction time	3.00 s	-
Kill assessment time	6.00 s	-
Terminal attack altitude	-	3.00 m
Maximum detection range for tracker		15000.0 m

Calculations

Threat missile

Speed	speed	=	0.90 Mach
		=	297.00 m/s

(assumes speed of sound is 330m/s)

	Range	Time
Profile	15000.0 m	0.0 s
	0.0 m	50.51 s

Engagement Envelope

Maximum Range	6000.0 m
Minimum Range	500.0 m

This data needs to be plotted on the graph

Time	Max	Min
0.0	6000.0	500.0
75.0	6000.0	500.0

Scenario Development

1)
First Detection occurs at 15000.0 m

At this point THREAT ASSESSMENT starts for a period of 6.0 s

This data needs to be plotted on the graph

Range	Time
0.0	6.0
16000.0	6.0

2)
Following THREAT ASSESSMENT a weapon REACTION TIME is required 3.0 s

This data needs to be plotted on the graph

Range	Time
0.0	9.0
16000.0	9.0

3)
The system is now ready to fire but must determine if and when the threat is within range
If possible the target should be engaged at the maximum range of 6000 m

This is calculated by considering the outgoing defensive missile profile

Defensive Missile speed = 2.0 Mach
= 660.0 m/s
(assumes speed of sound is 330m/s)

Defensive Missile Profile

This profile is a line of the form y=mx+c

Where m is the gradient of the line determined from the missile speed
c is the time at which the missile is fired

missile speed is 660 m/s therefore m = 0.00151515

The firing time for missile 1 is then determined by calculating the intersection of the two profiles and ensuing it occurs at a range of 6000m

if we denote the x position (range) of the two missiles as Xm and Xt
and the y position (time) of the two missiles as Ym and Yt
where m represent the defensive missile
t represents the target

we see that Xm = Xt = 6000
and Ym = Yt

The resulting set of equations can be solved to find the fire time for missile 1

Fire time missile 1 21.21 s

Missile one is fired at this time

	Fire Time	Range	Time
Missile 1	21.21	0.0 m	21.21 s
		6000.0 m	30.30 s

4)
The time before launches has to be left before the second missile is fired 1.20 s

Additionally the range/time of impact has to be calculated
This is done be equating the equations describing the lines

Range of impact 5754.21 m

	Fire Time	Range	Time
Missile 2	22.41	0.0 m	22.41 s
		5754.21 m	31.13 s

5)
The defensive system operated in a two missile salvo mode
It is now necessary to carry out kill assessment 6.00 s

This data needs to be plotted on the graph

Range	Time
0.0	37.1
16000.0	37.1

6)
The second salvo can now be launched if still within range

Range of impact 2739.45 m

	Fire Time	Range	Time
Missile 3	37.13	0.0 m	37.13 s
		2739.5 m	41.28 s

leaving a time before launch of 1.20 s

Missile 4 launched at 38.33 s

Range of impact 2493.66 m

	Fire Time	Range	Time
Missile 4	38.33	0.0 m	38.33 s
		2493.7 m	42.11 s

7)
The defensive system operated in a two missile salvo mode
It is now necessary to carry out kill assessment 6.00 s

This data needs to be plotted on the graph

Range	Time
0.0	48.11
16000.0	48.11

8)
A further salvo can be attempted if within range

Range of impact 490.80 m

This is below the minimum engagement range and so is not possible.

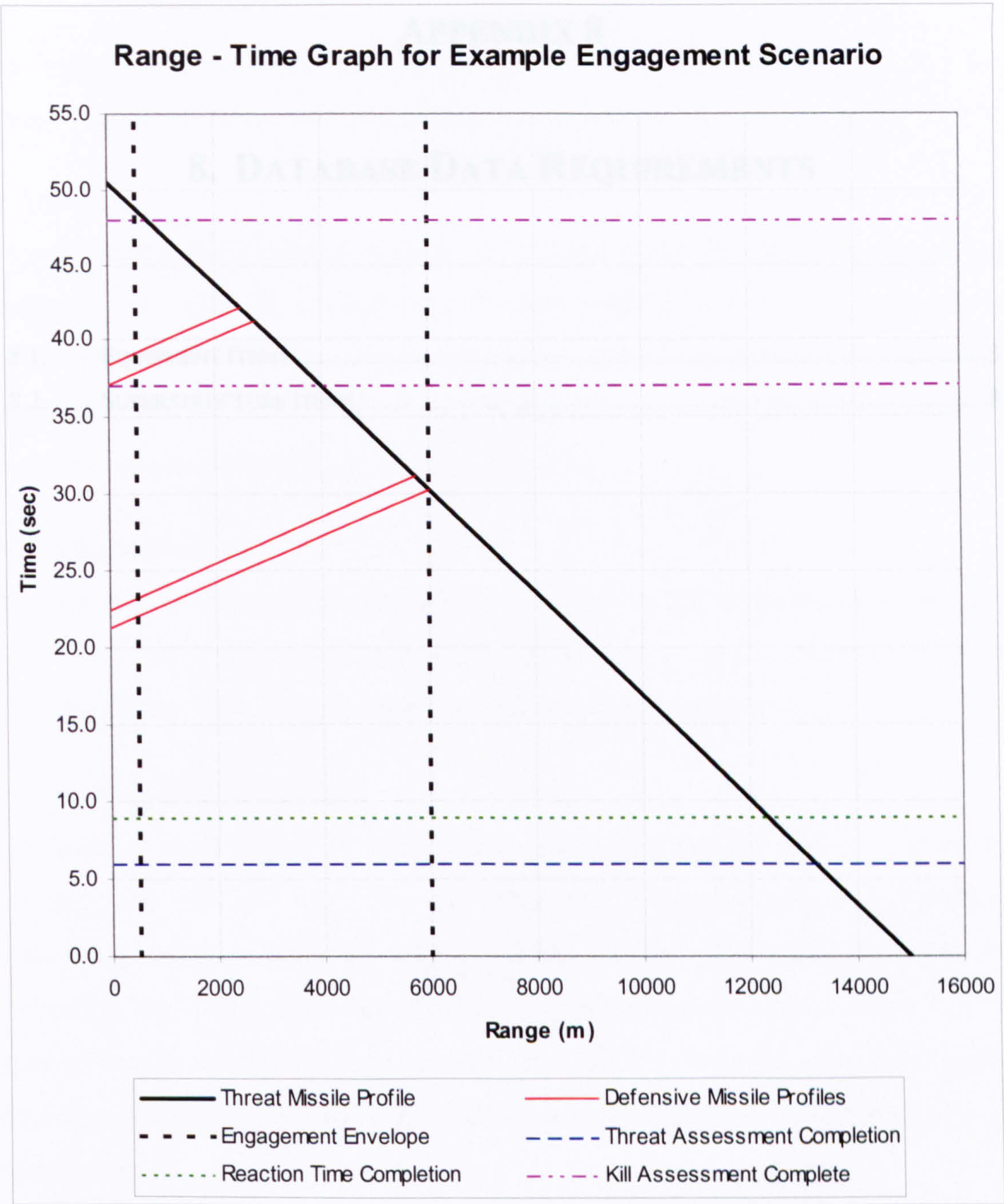


Figure A7.1 : Range - Time Graph for Example Engagement Scenario

APPENDIX 8

8. DATABASE DATA REQUIREMENTS

8.1. Equipment Items

The equipment item definitions are fixed within the database but there is a large range of different items, requiring different data to be stored.

a) Radar

All radar equipment should be recorded in this part of the database. The type of radar needs to be recorded, for example search radar or navigation radar, as well as details on the radar operation. This should include information about operating ranges and frequencies and any information about permissible separation that is not captured as part of the graphical model.

b) Communications

This section of the data should contain details on all available communication equipment, this is for both transmitters and receivers. Details are required on the operating frequency ranges to ensure the full band range is covered.

c) Tracking and Targeting

The database must record all information about the available systems for tracking and targeting, in some cases the particular tracker may be linked to a particular system, the database must reflect this. Other trackers are more flexible in their application and range from radar based systems to optical sights. These differing types of tracker have different data requirements, the more complex radar trackers requiring information similar to the radar systems whereas optical sights require little information.

d) Aircraft and Services

As well as containing details of the individual aircraft or unmanned air vehicle (UAV), this section of the database must also contain details of the support systems required by each aircraft. This will consist of the flight deck requirements and the hanger size required for different levels of support for aircraft or the storage and launching requirements for the UAV.

e) Defensive Weapons

These systems may be gun based or missile based systems and will result in different data being stored for each type. Details of operating ranges and frequencies is required to allow informed choices to be made on layered defence.

f) Offensive Weapons

The offensive weapons can be further broken down into three types of system:-

- Anti Air Warfare (AAW)
- Anti Submarine Warfare (ASW)
- Anti Surface Warfare(ASuW) including land attack and Naval Gunfire Support (NGS)

For each of these systems the data requirement is similar, however a clear distinction is required between the different types to ensure choices are made to meet the defined role for the vessel.

g) Countermeasures

The complete range of countermeasures available must be stored in this section of the database, these range from physical systems through to electronic countermeasures. The data requirement for each type is different, for ECM the EMI data is important, whereas for physical measures, range and applicability must be recorded.

h) Replenishment at Sea

Modular systems are used on UK ships for RAS and these can be detailed in the database allowing a choice to be made of the available systems. The limitations are mainly geometric for these systems and will be captured in the graphical element of the data storage.

i) Boats

In a similar fashion to the aircraft section of the database, details of boats are held but also details of boat storage and deployment mechanisms. For each boat a variety of storage and deployment/recovery arrangements may be applicable and this must be reflected in the database.

j) Lifesaving Equipment

Applicable lifesaving devices can be detailed within the database, important information includes the deployment method and the number of personnel for which the item is designed. In combination with checklists this allows choice of correct numbers of systems

k) Miscellaneous Equipment and Services

In addition to those items already discussed a large amount of additional equipment is located on the topside of a ship. This section of the database allows details of this type of equipment to be maintained, this can range from simple stowages through to anchors and cables, access doors, hatches, lifts, vents and spaces required for mooring arrangements.

For all of the equipment items there is some commonality in the data requirement. Further specific data may be required for individual items. Within each breakdown discussed above the basic data requirements are shown below:-

System Name	- An identifying name for the system.
Description	- A description of the equipment item detailing its usage.
Type of System	- A field describing the type of system, this allows further breakdown within each of the main sections outlined above.
Detail Level	- This is the flag field allowing the two-tier database to be constructed. The major equipment items can be distinguished from minor items. This allows the minor item to remain hidden until a detailed level of design is started.
Figure	- A figure showing the equipment item. This allows the main features of the item to be seen. Two figures could be shown, one of the equipment item, the second showing how it is represented within the system.
Requirements	- This details the requirements of the system and where other items are required. The database should be constructed so to ensure only valid combinations can be made.
Weight and Space Data	- A series of fields containing the weight and space data required by any companion system such as SURFCON [Dicks 98], [Dicks 00].

Graphical Layer Information	- A series of records containing description of any graphical data held as part of the model. This is where information about access, exclusion zones, efflux zones and any further layer information is recorded. This information is captured as part of the graphical model, but the basis for the information must be recorded here. In addition to layer information details on the exclusion envelopes for the items used to construct BAM diagrams is required (Section 7.2.1).
Electromagnetic Information	- For any system emitting electromagnetic radiation the frequencies and ranges must be recorded. This allows their inclusion in any EMI analysis that is undertaken (Section 5).
Scenario Information	- See Section 7.3 and Appendix 6.
Notes	- Allows further general notes to be made about suitability of the equipment.

8.2. Superstructure Items

All superstructure items are contained in this part of the database. These items are defined in a generic sense allowing the user a choice of different types of block, the actual dimensions are then fixed according to the particular design.

a) Superstructure Block

These records contain generic shapes describing different types of superstructure block, they can range from a simple box shape, through L-shaped blocks and further more complex shapes. They are used to define the major structural shape of the topside. In addition certain elements, such as the bridge, will be included as part of the superstructure definitions, allowing choices to be made and the particular compartments placed into the design space.

b) Funnels and Exhausts

A variety of different funnel and exhaust designs can be captured, the final sizes depending upon the ship in question. Particular dimensions are applicable to engine fits and so informed choices can be made. Data can also be captured, where known, on plume temperatures and trajectories for inclusion in the graphical model.

c) Masts

Masts are important sites for many equipment items and some structure is required in order to allow placement of these items. Different mast designs should be available, ranging across different geometries of existing mast types to proposals such as the Integrated Technology Masts (ITM) [Westacott 97], [Treen & Alger 00].

d) Deck Structure

There must be the facility to detail the deck structure and associated main bulkheads as this will impact on the possible topside and superstructure arrangements. The shape as well as the position of the bulkheads is important.

e) Miscellaneous Superstructure

This part of the superstructure database contains items required in an overall design such a bridge wings, weapon platforms and walkways. These are described in a generic fashion with the final sizes being entered by the user to fit with the design.

For all of the superstructure items the data requirements are similar and are summarised below:-

Type	- An identifying name for the superstructure element.
Description	- A description of the superstructure element.
Figure	- A figure showing the superstructure element. This allows the main features of the item to be seen.
Dimensions	- These are the dimensions available to the user that describe the shape in question, they consist of length, breadth and depth figures as well as an angle of slope for the sides (for RCS purposes). The range of dimensions available is restricted where appropriate, for example in the minimum diameter for a particular funnel, to ensure the user does not modify a valid shape making it invalid.

APPENDIX 9

9. ANIMATIONS

9.1. Submarine Design

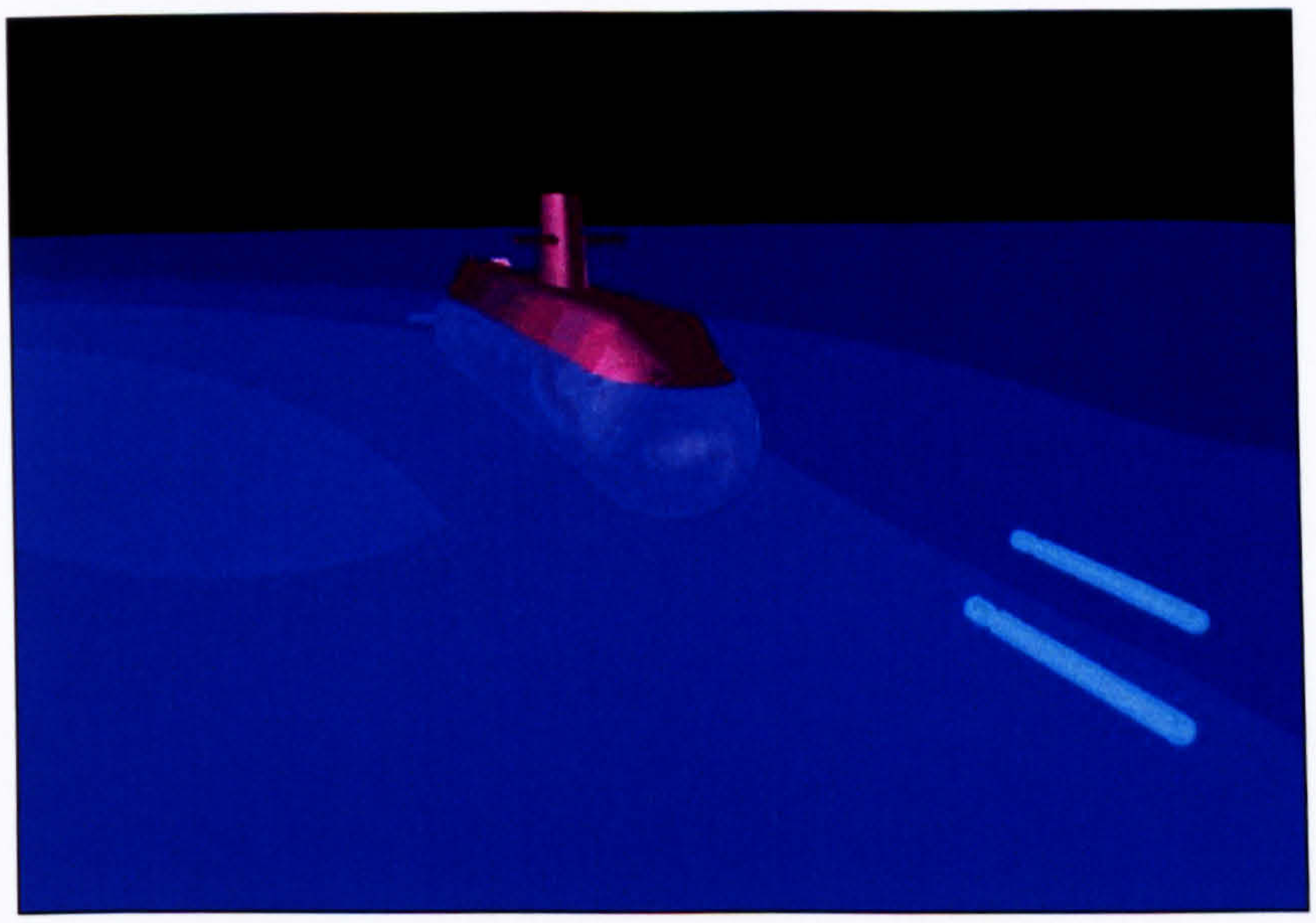


Figure A9.1 : Graphic taken from the Submarine Design Animation

The animation file is presented in three different resolutions[156] in AVI format[157].

9.2. Trimaran Aircraft Carrier Design

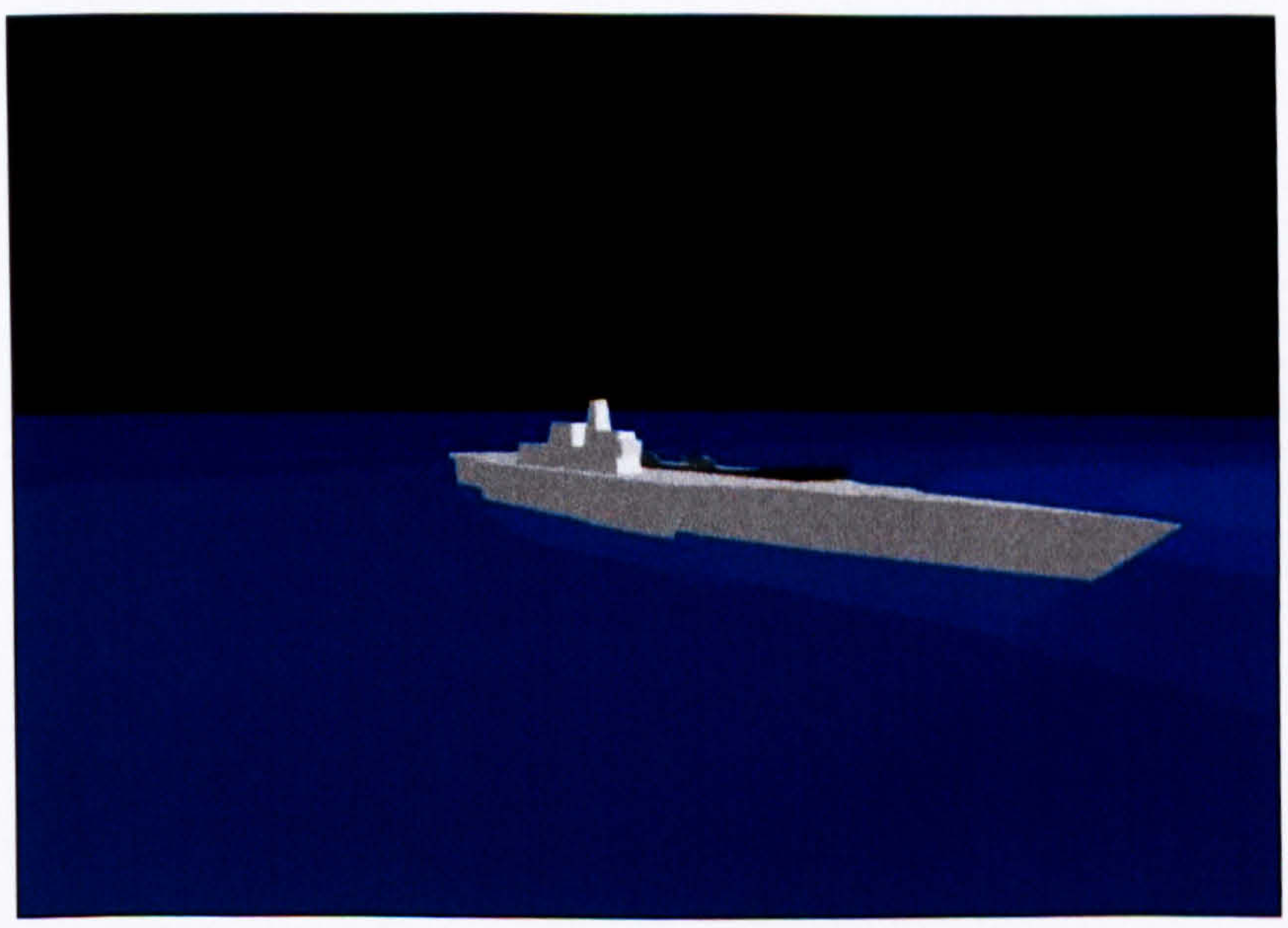


Figure A9.2 : Graphic taken from the Trimaran Aircraft Carrier Animation

The animation file is presented in three different resolutions[156] in AVI format[157].

[156] The accompanying CD contains three subfolders, one for each presentation. Within each subfolder three AVI files of differing resolutions are presented, 640 x 480, 800 x 600, and 1024 x 768.
[157] These presentations are best viewed using Microsoft Media Player under a version of the Microsoft Windows operating system.

9.3. Future Destroyer Design

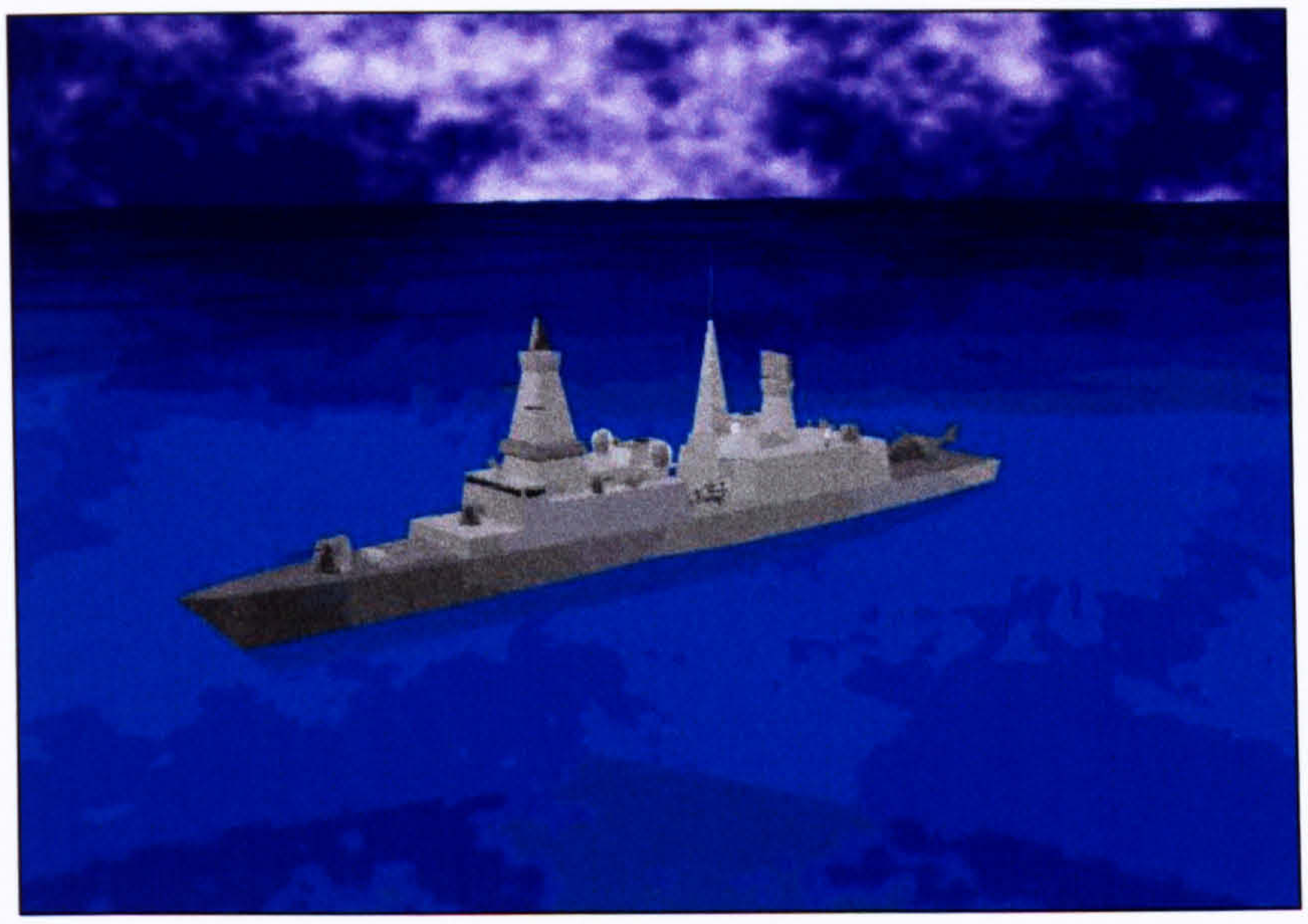


Figure A9.3 : Graphic taken from the Future Destroyer Animation

The animation file is presented in three different resolutions[156] in AVI format[157].